NOVEMBER 1989

SPACE RESEARCH AND DEVELOPMENT SERIES

AN ASSESSMENT OF POTENTIAL MARKETS FOR SMALL SATELLITES

(NASA-T[illegible]-10[illegible]) AN ASSESSMENT OF POTENTIAL N9[illegible]-14[illegible]
MARKETS FOR SMALL SATELLITES (NASA) 114 p
CSCL 22[illegible]
Unclas
G3/15 02[illegible]

Lawrence H. Stern
Kevin J. Lacobie
Zenon X. Zygmont

Department of Economics
George Mason University
Fairfax, Virginia

Virginia's Center for
Innovative Technology

AN ASSESSMENT
OF POTENTIAL MARKETS
FOR SMALL SATELLITES

Lawrence H. Stern, Kevin J. Lacoble, Zenon X. Zygmont

Department of Economics
George Mason University

AN ASSESSMENT OF POTENTIAL MARKETS FOR SMALL SATELLITES

Lawrence H. Stern, Kevin J. Lacobie, Zenon X. Zygmont

Department of Economics
George Mason University

Copyright © 1989 by the Center for Innovative Technology

Published by Virginia's Center for Innovative Technology
Space Research & Development Series

CIT Tower, Suite 600
2214 Rock Hill Road
Herndon, Virginia 22070 U.S.A.

Library of Congress Catalog Number: 89-51915
ISBN: 0-9625101-0-6

TABLE OF CONTENTS

I. Introduction 3
II. The Concept of Small Satellites 5
III. Small Satellite Functional Differentiations 6
IV. Development of the Industry 7
V. Current State of Production 16
VI. Small Geostationary Satellites 31
VII. Communications Satellites 38
VIII. Remote Sensing 44
IX. Location Determination 46
X. Microgravity 48
XI. Academic 53
XII. Technological Developments 54
XIII. Assessment 55
XIV. Conclusions 62
XV. Bibliography 68
XVI. Acknowledgements 76

Appendicies

Appendix A: Manufacturers of Small Satellites
Appendix B: Customers and Contracts for Small Satellites
Appendix C: Launch Vehicles and Launch Options
Appendix D: Producer Questionnaire
Appendix E: Customer Questionnaire

PREFACE

Virginia's Center for Innovative Technology is pleased to present the final report of its small satellite market assessment project. CIT sponsored this work, conducted at the Center for the Study of Market Processes, George Mason University, Fairfax, Virginia, in support of our space industry development initiatives.

In 1988, CIT presented the report of the Virginia Governor's Commercial Space Group, which identified several areas of opportunity for the development of space industry within the Commonwealth. The satellite industry, and associated supporting industries such as launch vehicles and launch services, were identified as important areas of opportunity. This study is but one component of Virginia's on-going research and industrial development activities associated with small satellites. Other initiatives include the *VaSTAR* small satellite program, and several technology development and demonstration projects being sponsored jointly by CIT and its corporate partners in Virginia universities.

As shown in this study, small satellites are becoming increasingly capable, owing largely to advances in electronics, computational systems, and other disciplines which support hardware miniaturization. This trend towards more capable systems in relatively small packages is causing mission planners to re-think the way they approach their space hardware needs, and is creating new applications areas in which small satellites can be used in innovative ways. The result is a potential growth market for the small satellite industry.

Michael W. Miller
Stephen L. Morgan
Series Editors

Herndon, Virginia

FOREWORD

This study was sponsored by a grant from the Virginia Center for Innovative Technology's Space Research Fund. The study describes current activities in the design and development of small satellites and their services.

Our research subjects include: a) the history of the satellite industry; b) current activities of satellite manufacturers; c) complementary inputs to small satellites, such as launchers and ground control; d) functional requirements that could be met using small satellites; e) potential users of small satellites; f) availability of various technologies; g) existing market projections; and h) other factors that might enable small satellites to be commercially successful. We also address potential difficulties of small satellite development and production. The industry faces possible technological constraints, such as the inability to exploit economies of scale or scope, and also faces political constraints.

The study was conducted through a review of the existing literature and interviews with satellite manufacturers and customers, other industry officials, government officials, and academicians. The data contained in this report have largely been obtained from them. However, the conclusions are solely the responsibility of the authors.

We hope to have created a qualitative study of the small satellite industry and its future market potential that will be useful to the industry and to others who wish to assess the market for small satellites.

Lawrence H. Stern
Kevin J. Lacobie
Zenon X. Zygmont

Fairfax, Virginia
September 1989

I. INTRODUCTION

In the past four to five years, small satellites, popularly dubbed "LightSats," have received a great deal of attention. The idea of using smaller and simple satellites is especially popular in military circles. Survivability, assured access to space, and lower systems costs have made small satellites a popular idea. A proliferation of small communications or sensing satellites seems potentially more survivable, subject to less degradation, and possibly more cost effective than a few large satellites.[1] Spearheaded by the Department of Defense's Defense Advanced Research Projects Agency (DARPA), the military community is conducting studies, some of which include fabrication for flight demonstration, of small satellites. In addition, NASA and other scientific users have independently started a trend toward smaller systems, which have always been paramount in amateur radio and university environments. Some commercial ventures have also caught the spirit of small satellites.

These military projects use proven technologies and standardization, and have short production times[2] and much lower costs than the normal government procurement contract. Commercial satellite users find such qualities advantageous. Smaller systems seem more able to attract venture capital than massive, complex systems. Small systems are more within the realm of the free enterprise system than the typical projects that dominate military and scientific space projects.

---

[1] While some military satellites cost less than $100 million and weigh less than 3,000 pounds dry, current military satellites can be over 10-15 tons, and cost in excess of $500 million.

[2] Some projects have been completed in 8-10 months.

PAGE 2 INTENTIONALLY BLANK

PRECEDING PAGE BLANK NOT FILMED

This study seeks to determine whether small satellites are commercially feasible. The issue is broader than mere demand for the product. It also involves the small satellite industry structure and the complementary capital structure that supports it.

Studying a single product, technology, or segment of an industry is not sufficient to assess the product's place in the overall market. An output, be it a product or a new technology, does not exist in a vacuum. The output is part of an infrastructure, composed of inputs that themselves are in a network. Only by examining the capital structure as a whole can the commercial feasibility of a single component be properly evaluated.

A capital structure is a complex network of complementary and substitutable inputs and outputs in the production of a particular good. The network is continually changing, especially in a new and dynamic industry. Suppliers, production techniques, potential users, and the products themselves are constantly in flux. A great deal of particular knowledge about the capital structure, which is usually scattered among various firms in the industry, is essential to an accurate evaluation of the industry's potential.[3] For example, fatsats and smallsats will create very different arrangements of the whole capital structure.[4] The "viability," i.e., the market participant's ability to provide a particular service without massive subsidies, requires examining the significant parts of the whole structured network.

---

[3] For more details in the capital structure approach, see Ludwig Lachmann, *Capital and its Structure*, (Sheed Andrews and McMeel, Inc., Kansas City: 1978 [1956]), and Stephen Morgan, "A Framework for Analyzing the Market and Supporting Infrastructure for Small Satellites and Associated Systems," *Proceedings of the 2nd Annual AIAA/USU Conference on Small Satellites*, (1988), hereafter referred to as *1988 Utah State Conference*.

[4] An alternative to the current satellite approach is "fatsats", that is, making the satellite even larger, foregoing delicate and expensive techniques to shave weight off components of the satellite structure. But what impact will Fatsats have on the infrastructure? - Even bigger launchers, with concomitant increases in launching sites, higher insurance, more pollution, etc.

II. THE CONCEPT OF SMALL SATELLITES

There is no consistent definition for "small satellites." Definitions range from satellites weighing less than 500 pounds to those weighing 3,000 pounds. Small satellites are sometimes defined by cost, i.e., satellites costing less than $20 million including the bus, payload, and launch vehicle.[5]

The meaning of small satellite is often in the eye of the beholder, which in many cases is the customer. Some customers define them by cost,[6] others by high technology, or the capability of being deployed in clusters by a launch vehicle, or anything that can be launched on the Pegasus or the proposed Standard Small Launch Vehicle (SSLV).

For purposes of this study, we have generally studied satellites weighing less than 1,000 pounds. In certain cases, such as microgravity satellites and small geostationary satellites, we have included information on satellites up to 3,000 pounds.

---

[5] 500 Pounds, DARPA, June 1989. 1,000 Pounds - Proposed capability of DARPA small standard launch vehicle and NASA small class launch vehicle procurement. 3,000 - Pounds, Space Commerce, U.S. Department of Commerce, May 1988. 1,000 Kilograms - SAIC, July, 1989; Lewis Research Center contract specifications. $20 million - Lockheed 6/26/89; Rockwell, 6/28/89.

[6] Less than $2 million to build and $2 million to launch.

III. SMALL SATELLITE FUNCTIONAL DIFFERENTIATIONS

Small satellites come in many shapes and sizes, from microsats to the larger microgravity satellites. They are designed to fly in geostationary, low earth, and elliptical orbits, and to cover various parts of the globe. They can serve many functions including remote sensing, position location, and military applications.

Commercial uses generally fit in the following categories: communications in geostationary orbit, communications in low earth orbit, remote sensing, position location, microgravity, academic, scientific, and technology development.

Viewed in a graphic form, these include:

FUNCTION ORBIT	Communications	Remote Sensing	Position Location	Micro Gravity	Academic-Scientific	Technology Development
175/600 Miles	X	X	X	X	X	X
Elliptical or Molniya	X					
Geo-Stationary	X		X			
Circular 1/2 Geo			X			

Table A: Orbit/Function Matrix

The current uses of small satellites have developed rather rapidly over the past four or five years. However, the beginnings of small satellites extend from the 1950s. The industry's historical development is useful in evaluating the future of commercial development.

IV. DEVELOPMENT OF THE INDUSTRY

Small Satellites in the History of Space

> "Small satellites once formed the backbone of the U.S. space program. They are now being rediscovered for useful and critical missions, for the demonstration of new technology, and for the training of engineers and scientists."[7]

Almost twenty years after Tsiolkovsky first suggested artificial earth satellites in 1926 and multistage rockets in 1928,[8] the Naval Research Lab (NRL) discussed the possibility of using satellites as research platforms, but the plan was never implemented because of prohibitive cost constraints[9] and the Defense Department's lack of interest.[10] However, rocket research was begun in earnest and "[b]y the early 1950s studies had been made [by the Navy Bureau of Aeronautics and Rand which] indicated rather conclusively that a multiple-stage rocket launcher capable of putting a small satellite in orbit could be designed using only moderate extensions of existing technology."[11]

Although proposals to design and launch satellites were prevalent during this period[12] -- including those for the 100 pound Minimal Orbital Unmanned Satellite Experiment (MOUSE),[13] the 11 pound Project

---

[7] Eric J. Hoffman, "Lightsats and Cheapsats: The Engineering Challenge of the Small Satellite," (Johns Hopkins APL Technical Digest, July-September, 1988) p.298.

[8] Homer E. Newell, Beyond the Atmosphere: Early Years of Space Science, (NASA, Washington, DC, 1980),p.28.

[9] Newell (1980, p.33).

[10] Eugene M. Emme, A History of Space Flight, (Holt, Rinehart & Winston, New York, 1965),p.105.

[11] Richard W. Porter, The Versatile Satellite, (Oxford University Press, Oxford, 1977),p.2.

[12] See Emme (1965, pp.114 ff).

[13] Designed to carry scientific instrumentation, MOUSE was proposed by S. Fred Singer in 1953 (Newell, 1980, pp.52-53).

Orbiter, and Project Vanguard[14] -- it was the ballistic missile program and the scientific community's intention to fly a rocket during the International Geophysical Year (IGY) that paved the way for civilian use of space.[15] Many of the ballistic missiles developed during this period, including the Atlas, Thor, and Titan, were later applied to civilian programs.[16]

Although the Secretary of Defense had previously rejected work on the Orbiter, it was reauthorized in 1955 as a precautionary measure should the approved Vanguard experience problems.[17] This decision proved fateful, because the Vanguard effort failed in December 1957. The experience shows the advantages of running parallel development programs for new technology.

Because of limited launch capability and high relative launch costs, satellites were necessarily small and light: "[I]n the early days, every satellite was a lightsat; launcher capacity did not permit otherwise".[18] The first successful vehicles deployed by the Soviet Union and the United States -- Sputnik 1 on October 4, 1957 and Explorer on January 31, 1958 -- were both small satellites.[19] However, the United States Defense Department was later unable to take advantage of the knowledge generated by the Explorer's success. The Department did not place a communications satellite in geosynchronous orbit. The cancellation of the Advent program, because of overruns, amounted to a communications satellite development default to the civilian sector.

---

[14] Orbiter and Vanguard were projects of the Army and Navy to demonstrate the International Geophysical Year satellite.

[15] Albert D. Wheelon, "The Rocky Road to Communications Satellites," (The Von Karman Lecture, AIAA 24th Aerospace Sciences Meeting, January 6, 1986),p.2.

[16] AIAA/DARPA Meeting on Lightweight Satellite Systems (Naval Postgraduate School, Monterey, CA, August, 1987),p.169. (Hereafter referenced as AIAA/DARPA).

[17] Porter (1977, p.3).

[18] Allen E. Fuhs and Marty R. Mosier, "A Niche for Lightweight Satellites," (Aerospace America, April, 1988),p.14.

[19] 184 and 10 pounds respectively.

Nevertheless, during the first decade of space exploration small satellites were used in many ways. Basic science (Pioneer and Explorer), weather observation (Tiros and Environmental Sciences Services Administration, civil communications (Telstar and Syncom), military communications (the Initial Defense Communication Satellite Program), and ocean navigation satellites (the Transit series) were among the uses of small satellites during the 1950s and 1960s.

As Table B for the Explorer class satellites indicates, it is apparent that frequent missions characterized the early period of U.S. space policy. For Explorer alone, in the ten year period 1959-1968, 40 satellites were launched, primarily as payloads on Scout or Delta launch vehicles.

YEAR	DESIGNATION	WEIGHT (kg.)	LAUNCH VEHICLE
1959	Explorer 6	64.4	Thor-Able
1959	Explorer 7	41.5	Juno II
1960	Explorer 8	40.8	Juno II
1961	Explorer 9	36.3	Scout
1961	Explorer 10	35.4	Thor-Delta
1961	Explorer 11	43.1	Juno II
1961	Explorer 12	37.6	Thor-Delta
1961	Explorer 13	83.9	Scout
1962	Explorer 14	40.4	Thor-Delta
1962	Explorer 15	45.4	Thor-Delta
1962	Explorer 16	100.7	Scout
1963	Explorer 17	185.5	Thor-Delta
1963	Explorer 18	62.6	Thor-Delta
1963	Explorer 19	43.1	Scout
1964	Explorer 20	44.5	Scout
1964	Explorer 21	61.7	Thor-Delta
1964	Explorer 22	52.2	Scout
1964	Explorer 23	133.8	Scout
1964	Explorer 24/25	8.6/40.8	Scout
1964	Explorer 26	45.8	Thor-Delta
1965	Explorer 27	60.8	Scout
1965	Explorer 28	59	Thor-Delta
1965	Explorer 29	174.6	Thor-Delta
1965	Explorer 30	56.7	Scout
1965	Explorer 31	98.9	Thor-Agena
1966	Explorer 32	220	Thor-Delta
1966	Explorer 33	93.4	Thor-Delta
1967	Explorer 34	73.9	Thor-Delta
1967	Explorer 35	104.3	Thor-Delta
1968	Explorer 36	208.7	Thor-Delta
1968	Explorer 37	88.5	Scout
1968	Explorer 38	275.3	Thor-Delta
1968	Explorer 39/40	9.4/71.2	Scout

Table B: EXPLORER MISSIONS[20]

---

[20] Compiled from Linda N. Ezell, NASA Historical Data Book, Vol.II (NASA, Washington, DC, 1988), pp.237-253.

The Trend to Larger Satellites

The trend toward larger satellites resulted from more powerful rocket propulsion systems, which in turn was motivated by competition in space exploration with the Soviet Union. In retrospect, this trend is not surprising. Just as the size of the primitive satellites were constrained by booster payload capability, the latter's increase in performance enabled the former to expand in tandem. The decision to push for larger and more powerful propulsion systems like Saturn, was a conscious one, which contributed to the successful Apollo program.

While space budgetary limitations were less constrained during the 1960s than they are today, the focus on fewer missions gradually reduced the accessibility to payloads.[21] The policy moved from a "larger number of separate space programs that were launched frequently, with shorter mission lifetimes"[22] to one that reduced the number of programs, increased time between launches, and maximized the number of missions each space craft performed.

The outcome of this process was a capital structure that was inflexible and vulnerable to long delay. The Challenger catastrophe and the large ELV failures brought U.S. space activities to a virtual standstill.

The Challenger accident demonstrates the vulnerability of relying on one particular space technology; it can cripple even the most sophisticated space program. The accident may even call into question the utility of having technology policies which unduly centralize decision making. Mistakes can be unnecessarily large and costly, and central decisions run the risk of hampering the knowledge generation process inherent in scientific, market, and interagency competition.[23]

---

[21] Though not without protest from the scientific community. The trade-off between fewer larger or more smaller missions has been a point of debate within the space science community from the beginning (Newell, 1980, p.124, p.162).

[22] W. David Thompson, "Small Satellite Force Enhancement" mimeo (Small Satellite Manufacturers Association, El Segundo, CA. 1989), p.1.

The accident aside, the competition with the Soviets and the centralized decisions have created an industry limited to a few highly-complex missions each year. The resulting firms tend to be large, high-cost enterprises that are relatively inflexible. As M.N. Sweeting has written:

> Space missions have become synonymous with large budgets and long timescales, executed by national industries or government agencies promoting ever-larger space structures to carry exotic instrumentation or commercial payloads. The financial burden of supporting these space missions has greatly limited direct access to the space environment to only the most committed of nations and agencies. It has become virtually impossible for new ideas, technologies or services to be evaluated in orbit without a protracted lead-time, often resulting in operational obsolescence.[24]

Contemporary Advocacy for Small Satellites

Because small satellites are perceived to encompass "low cost, flexibility, and ease of construction,"[25] a range of users in the private and public sectors have embraced them. DARPA sponsored Global

---

[23] STS imposed a new set of constraints on users of small satellites. Launching on STS, while nominally "costless," included hidden costs in the form of schedule delays, quality and environmental requirements, and a new set of paperwork hurdles. See, for example, Table F-1, National Research Council, 1988, p.48. After the Challenger accident, small satellites users were further constrained by the absence of regularly scheduled ELV flights. For further elaboration on how market systems convey knowledge see Friedrich A. von Hayek, Individualism and Economic Order. Routledge & Kegan Paul, London, 1949.

[24] M.N. Sweeting, "Cost Effective Spacecraft Engineering in Low Earth Orbit Satellites," (in Satellite Communications Systems, B.G. Evans (ed.), Pete Peregrinus., Exeter, UK, 1987), p.358.

[25] William J. Broad, "For Cheap Versatile Spacecraft, Designers Discover Less is More," (New York Times, May 22, 1987).

Low Orbiting Message Relay Satellite (GLOMR) fostered much of this perception. GLOMR "[d]emonstrated that a militarily useful satellite could be designed, developed tested [sic] and launched in less than one year and for less than one million dollars."[26] GLOMR provided the proof of concept of a "simple, low cost spacecraft that could be built rapidly with off-the-shelf avionics components."[27] This success reinforced other, less publicized endeavors like the Volunteers in Technical Assistance's digital communication experiment,[28] which was carried aboard UoSat 2 in 1984, and NuSat in 1985.

Prior to GLOMR, university, scientific, and amateur users pursued small satellite technology. The Applied Physics Laboratory at Johns Hopkins developed Transits, Polar Bear, and HiLat; the Radio Amateur Satellite Organization developed OSCARs 6, 7, and 8, which included search and rescue capability; the University of Surrey developed UoSat 1 and 2, Utah State developed NuSat, and the Naval Postgraduate School developed the Orion bus. These organizations continue to work on small satellites, and focus the continuing discussions on small satellite technology.

The feasibility of building small satellites has been enhanced by the work of small commercial firms such as DSI, Intraspace, and Globesat. Their vision of commercial space activity includes small satellites. The confluence of the early advocates and the entrepreneurs which has made small satellites a reality, has even carried over into the military community.[29]

---

[26] AIAA/DARPA, (1987, p.4).

[27] Ardak Corp., Global Low Orbit Message Relay Satellite (GLOMR): Final Technical Report, (Ardak Inc., McLean, VA, 1986), p.1. GLOMR, "was to have the capability to store and forward packetized data messages using low cost ground user communications equipment" (ibid).

[28] The Digital Communications Experiment demonstrated "the first non-military application of 'store and forward' packet radio technology."

Small satellites have benefitted from commercial launch vehicles of the mature firms -- such as Arianespace, General Dynamics, Martin-Marietta, and McDonnell Douglas -- and of recent start ups, such as American Rocket Corporation, Orbital Sciences Corporation, and Space Services. A cost-effective means of launching small satellites is a critical part of their inevitable commercial success or failure.

Most recently, the primary impetus behind small satellites has been the military.[30] Battlefield commanders want to maintain low altitude monitoring and communication. Tactical commanders want a non-labor intensive small satellite that could be launched with minimum effort. Commanders envision small satellites as a new battlefield asset, providing support that generally has not been available from large satellites.

Small satellites can also complement existing large satellites, as illustrated by plans to provide a degree of redundancy to the military communications network. They provide, "a series of smaller, lower-cost space vehicles designed for specific missions which augment, rather than compete with, the current force structure."[31] If the demand for small satellites becomes sufficiently large, mass production could drive the cost down significantly.

---

[29] "Low orbiting, inexpensive satellites for communications and other spaceborne missions are receiving renewed interest. This is especially true as the trend continues in geosynchronous satellites towards increased size and cost. Budget restraints in programs and systems are forcing users to lower costs and simpler mission solutions. Other advantages of low orbiting satellites are that they are more dynamic, less susceptible to jamming and synergistic with modern packet switched data networking systems." (ARDAK, 1986, p.21).

[30] Broad, 1989; Theresa Foley, "U.S. Will Increase Lightsat Launch Rate to Demonstrate Military, Scientific Uses," (Avation Week & Space Technology, September 26, 1988); Hoffman, 1988; William Howard, "Cheaper by the Dozen," (Naval Institute Proceedings, February, 1989).

[31] Thompson, (1989, p.8).

In response to the renewed interest of the military, several programs derived from the small satellite initiative have resulted, including the DARPA's Lightsats, Navy's Special Purpose Inexpensive Satellites (SPINSATs), the Air Force Multiple Satellite System (MSS) program, Reserves, Scientific Technology Experiment Program (STEP), and NASA's PegSat and Small Explorer (SMEX). Each agency has its own objectives in mind. For example, Dr. William Howard (Naval Space Command) recommends that satellites be designed for each agency's specific tasks, initially primitive but growing in sophistication.[32] The tenure of Air Force Secretary Edward C. Aldridge aside, it is no longer potentially detrimental to one's career to champion small satellites as another asset in the military arsenal, or to suggest markets in the civilian sector.[33]

Hoffman argues that smallsats will serve to verify new space technology without putting major programs at risk. He characterizes the small satellite philosophy as, "build a little, test a little, learn a lot."[34] Commercially small satellites "could reduce the amount of capital at risk and cut the time required for a positive return on investment."[35] Furthermore, the small size helps small businesses make in-roads into defense procurements. If defense budgets for small satellites remain lean, large scale capital accumulation may not be necessary to compete for contracts, leaving opportunities open for small businesses.

---

[32] Howard (1989, 71)

[33] When the Air Force published its Request for Proposals for the STEP program, and Program Research and Development Announcement for Reserves, and Small User Milcomsat programs, small satellites not only gained respectability, but established spacecraft manufacturers began designing busses for this market, looked at the methods and organizations used by the entrepreneurial firms and in some instances, obtained equity interests in them or teamed with them in responding to the proposals.

[34] Hoffman (1988, p.293). Similarly, the Final Report of the Microspacecraft Workshop Panel (Microspacecraft for Space Science Workshop, California Institute of Technology/Jet Propulsion Laboratory, July 7-8, 1988) mentions, "[t]he enabling feature of microspacecraft is ... that [they] will cost less ... and involve less risk than large spacecraft ..."

Groups like the International Small Satellite Organization and Small Space Manufacturer's Association, and conferences like the 1987 American Institute of Aeronautics and Astronautics meeting in Monterey and the yearly Utah State gatherings, will facilitate the transmission of knowledge about the strengths and weaknesses of small satellites.

From a broader technological view, small satellites hasten hands-on experience for college students. While the availability of experience is still limited,[36] the opportunity for budding scientists and entrepreneurs to construct a working satellite fosters the small satellite industry and space science in general.

V. CURRENT STATE OF PRODUCTION

Special Features in the Organization of the Industry

At the present time, there is much talk and little manufacturing in the industry. The small satellite as a commercial product is in its infancy. Several institutions are able to manufacture them, and some have been, or are currently being, built. But commercial use is still lacking. This may be due to a lack of demand, or it may be caused by an inappropriately organized industry.

---

[35] Hoffman, (ibid).

[36] Currently, Weber State University, the University of Surrey, Stanford, Applied Physics Laboratory's graduate physics curriculum, and military academies such as the Navy (Orion and Midsat) and the Air Force (Starsat) offer such experience.

The industry is presently organized so that firms rely on government expenditures. It is nearly impossible for a firm to establish a reputation for quality without obtaining a government contract. But obtaining a government contract enhances a firm's chances of gaining financial backer's acceptance. This peculiar fact is related to two problems a new space venture faces: credibility based on past performance, and the specificity inherent in most projects.

A new manufacturer of small satellites faces a Catch-22 in building a reputation. For investors in external financial markets, or upper management in internal financial decisions, past performance is a key indicator for the project's risk assessment. Yet, a successful record is difficult to establish without the ability to obtain financing for the project. An existing firm may face similar hurdles. Many of the interviewees for this study complained of financial conservatism, both externally from Wall Street, and internally from upper management, as the main barrier to development of new programs. Financiers, of course, are not always conservative, yet they do seem to be particularly conservative when associated with space.[37]

The conservatism of financiers is partly attributable to the satellite components' highly specific nature and the final product. For example, the assembled attitude control board for a Molniya-orbiting satellite will serve as little else, except perhaps a coffee tray. Therefore, both suppliers to the satellite manufacturer and the satellites buyer are put at risk, should the manufacturer fail to carry through or attempt to alter the contract.[38] The supplier may be left with a special-purpose instrument with little use to any other satellite project, let alone purchasable in the wider market. Furthermore, the satellite buyer may also arrange for other inputs to go along with its satellite purchase, plus resources put into detailed planning for the project. Without the satellites, many of these resources become scrap, saleable only at salvage value should the buyer abandon the project.

---

[37] See Scott Masten, "The Organization of Production: Evidence from the Aerospace Industry," The Journal of Law and Economics, 27:2 [1984] for a discussion.

When firms and individuals find themselves in such specific interrelationships, they often engage in what economists call "non-standard contracting."[39] In the small satellite industry, such contracting is quite standard. Precommitment contracts with suppliers,[40] detailed contracts with launch companies, NASA, or the Air Force for launch facilities,[41] co-ownership in supplier/producer stocks,[42] memoranda of understanding and other methods are used to interlace the plans and decisions of supplier/producer or producer/user. Such "nonstandard" relationships reduce the likelihood of one firm holding the other hostage.

---

[38] Sometimes called a "hostage" situation. If a supplier is making an input that is specific to only one buyer (i.e., only has scrap value should the buyer fall through), the buyer can exploit the situation by offering one price at pre-purchase time which will induce the supplier to commence production, then force a much lower price at delivery time. Mutual hostage taking can occur if both the input and the product are specific in purpose. Then both can hold the other's product hostage.

[39] See Williamson, *The Economic Institutions of Capitalism*, (The Free Press, New York, 1985). "Non-standard" to the economist, who includes as "standard" or "classical" contracting only purchase agreements specifying a) price, b) quantity, c) an easily describable product, and (maybe) d) delivery date and e) place.

[40] E.g., Intraspace's arrangements with its suppliers. See R.F. D'Ausilio, "Small Commercial Satellite T-Sat - Innovative Small Satellite Manufacturing Techniques", *AIAA/DARPA*, (1987), p.316

[41] E.g., Space Services Inc. (SSI) has with the Wallops Island facility in Virginia.

[42] E.g., TRW's 20% ownership in Defense System Inc. (DSI), the GEOSTAR and Sony Corporation, Telefonica de Espana, co-ownership arrangements, and the OSC/Hercules, OSC/Ball Aerospace arrangements.

These governance structures, which are the norm in the complex space industry, still do not eliminate risk. The manufacturer can go bankrupt. The high specificity and risk of failure, despite specialized contracts, leads to the aforementioned conservatism: not only financial unwillingness to back new projects, but the unwillingness of suppliers and users to risk their specific assets.

Commercial conservatism will be heightened where firms can obtain government funds to establish contractual reliability. A government contract leads to manufacturing experience and can indicate an ability to live up to contractual obligation. This establishment of credibility then can lead to the beginning of commercial success. The only drawback to this approach is that the resources needed to gain government contracts, and the corporate culture usually adopted, including good lobbyists, political savvy, an acceptance of big budgeting, and a no-risk or low-risk attitude, may induce the company to remain a sub-contractor or sub-unit of the government,[43] rather than become an active entrepreneurial firm.

The Impact of Publicly Generated Knowledge

Firms are not the only participants in the small satellite market. Some very significant universities and laboratories participate as well. As evidenced by the Small Satellites Manufacturers Table [Appendix A], some nine or ten educational or research institutions involve themselves in small satellite manufacturing. Their involvement has a significant impact on the emergence of a new industry.

---

[43] Referred to as "quasi-public" enterprise.

Work done in universities, public research laboratories, and professional associations often has important effects on emerging industries. Most of their work, be it grant-funded research, student projects, or dissertations, reaches the public domain[44] much faster than for-profit research. Furthermore, such institutions often lead the search for knowledge. Such knowledge is important to firms seeking new production methods and new demands for a market. In small satellites, the Radio Amateur Satellite Corporation (AMSAT) is one of the more exciting of these institutions. AMSAT has been making satellites since 1969 (and their precursor, Project OSCAR, since the late 1950s) and has to date made 13 small communications and scientific satellites. Four of these will be launched in cluster on Ariane at the end of this year.[45]

A number of universities have been involved in small satellite development. The Applied Physics Laboratory at Johns Hopkins University has produced 51 scientific, communications, and remote sensing small satellites.[46] Other universities have substantial student involvement, including projects, theses, and dissertations that study the production of small satellites. Weber State College in Ogden, Utah, and the University of Surrey, England, already have operational satellites available.[47] Other schools of note include Stanford University and the Naval Postgraduate School.

---

[44] Except for classified work done for the military

[45] AMSAT is for the first time marketing their product, the Microsat bus, through Interferometrics. But such action is only to raise money for further projects - the collaborative work of these eager engineers will not be compromised any time in the near future. Their eagerness is to work with leading edge technology, and in this area, have pushed such innovations as digital communications using packet radio.

[46] Artificial Earth Satellites Designed and Fabricated by the Johns Hopkins Applied Physics Laboratory, (APL, Laurel, MD:1987)

[47] Weber State's NUSat I, and University of Surrey's UoSat 1 & 2.

Institute	Recent Projects	Applications
CAST	HuSat	communications
StarLab	SURFER	tether appl.
Jet Propulsion Lab	L-GAS	exploration
Naval Postgraduate	PANSat	communication
Johns Hopkins' APL	Polar Bear	
Naval Research Lab	LIPS-III	tech. development
Tech. Univ. of Berlin	TUBSAT	education
University of Marbury	Phase III/OSCAR 10	amateur radio
University of Surrey	UoSat	comm., experiments

Table C: Universities in the Small Satellite Arena[48]

Like the collaborative work of AMSAT professionals, unclassified work from universities produces knowledge that reaches the public domain rather quickly. Innovations diffuse rapidly, and students often join or start new firms.

The Entrepreneurial Creation of Markets

Carrying this new knowledge to market is the entrepreneur's responsibility. This function occurs in the form of new firms, established firms seeking out new markets, and new projects developed in large firms.

New firms in the small satellite industry are important to the emerging industry's success. Current consumption is (by definition) lacking in an emerging industry -- it is the entrepreneurial vision and active creation of future demand that will fuel the industry. The small firms experiment, and succeed or fail. Their experience creates valuable information about demand for a new product that is spread through the industry.[49]

---

[48] See Appendix B for details.

Companies like Intraspace, Globesat, Ball Aerospace, DSI, Orbital Sciences Corporation and Astronautics are currently among the stronger entrepreneurial advocates for a small satellite industry. And while they are seeking out a real commercial demand, they survive on government study contracts, Independent Research & Development money, and fabrication projects. Lightsat fabrication has especially picked up in the past two years, as Table D illustrates:

Company	Project Name	Sponsor
Ardak	Profile	CNR
Astronautics	Alexis	Los Alamos
DSI	MAESTRO	Navy ONR
Globesat	SMEX	Goddard
OSC	VaSat	Virginia CIT
Intraspace	SALT	Navy ONR

Table D: Actual Government Study and Fabrication Contracts by Small U.S. firms[50]

Other companies are still at the paper stage, which is where almost all were just a few years ago with regard to small satellites. They have created a concept on paper, and entrepreneurial vision is behind it, but the firm is still looking for actual demand to materialize. Many small satellite projects have been started with

---

[49] The entrepreneurial acts of a project or lab manager in a big aerospace firm, through advocacy for their newly created technology, results in a similar fashion. An exception should be noted, however; the knowledge about the results of their advocacy (especially if they fail), internally to convince their corporation to venture in their direction may diffuse more slowly through the industry. Entrepreneurial acts are not only important to emerging industries. A mature industry, with seemingly stable demand (such as the defense industry), can rely more on routine and incremental improvements but can stagnate without entrepreneurial acts. Such stagnation can endanger long-term survivability, as the American automobile industry has learned.

[50] See Appendix B for details.

Independent Research & Development money. Some are now being advocated for commercial use.

The Culture of Established Firms

A third group in the small satellite industry is the large aerospace companies. While many of these companies have produced small satellites in the past, progress has been slow in this decade. In the past twenty-five years, their manufacturing capabilities, expertise, management style, and corporate culture have evolved to accommodate larger and more complex space systems. Personnel in these companies have said that their corporate culture is not attuned to small satellites. Their organizations are not structured to produce simple, fast, and inexpensive products.

Organizational style, and the culture around it, can become just as specific to certain capital structure combinations as a technical skill. This specificity is heightened by monopsony demand. The U.S. government sets up very specific quality control, accounting, and oversight requirements for their projects. The typical division of labor required to build big or mass-produced systems means that several separate corporate departments must meet to discuss work on a new project. A small satellite is only small in size -- it contains essentially the same number of functions a larger satellite might -- and therefore a new small satellite bus could require a meeting of just as many of the separate component departments in the firm: propulsion, battery, electronics, and even accounting and personnel. This is where much of the overhead occurs.

A certain corporate culture, a partly explicit but mostly tacit set of attitudes, goes with a certain organizational style. Enculturation, rigorous training, and particular personalities are required to assure the attainment and maintenance of a reliable product. The military and NASA demand such products. Such enculturation produces conservatism within the company, so internal advocacy for projects that take the company down a different cultural path, meets with resistance within the company.

The large, established firms have overhead structures and practices that reflect Department of Defense and NASA requirements for large complex items. By and large the firms are not tailored to produce small satellites.

Furthermore, a corporate culture often becomes a part of the firm's reputation. For example, Hughes Space and Communications is known for ultra-high reliability. Many large aerospace firms have created such ultra-high quality reputations for themselves from working to government standards.[51] Getting involved in projects of a different kind involves changes of internal attitudes and probably compromises the company's reputation. Small satellites typically have a shorter life and a lower calculated reliability with their technology derived from sounding rockets, ballooning, and terrestrial communications experience. Because of this, the large firms face standards different from their past production standards.

However, since the Air Force entered the small satellites market, the product is changing. Defensive survivability through proliferation is starting to gain currency,[52] emphasizing national security more than cheaper systems. If this trend materializes, smallsat may not mean differences in size, technology, and cost; it may simply mean differences in size. Military satellites built small to fit in as part of an overall survivable system could just be smaller, presenting lower value targets and more costly kill factors, but without any differences in technology from the larger satellites with which the large aerospace vendors are familiar. If so, these firms[53] will probably fill this niche in the growing small satellite market. Such a change in emphasis will create two different kinds of small satellites. Both will probably find a niche in any coming market.

---

[51] Such as Milstar specifications.

Current State of Complementary Inputs to Small Satellites

To study the industry structure, one must go beyond the product itself and examine its position within the capital network. The two significant complements to small satellites are launch facilities and ground stations. Also important are components for the satellite, such as their propulsion, power, telemetry, and attitude control systems. "Natural resources" critical to satellites include orbital slots and frequency assignments.

Launching

The most important complement to satellites is launching systems. Indeed, the availability of launching options circumscribes small satellite sizes, as has already been noted above [see Part III, The

---

[52] See Sparta Inc.'s, *Small Milcomsat study*, the DARPA Monterey meeting.

[53] They are already working on proposals and have received contracts from, the Air Force [see "Comm by the Yard" and "Reserves."

Concept of Small Satellites]. Thus, in the small satellite world, a preoccupation with launching systems is understandable. Three basic methods are available for small satellites:

1) The traditional way to put a payload into space has been to use expendable launch vehicles (ELVs). The vehicle of choice for the small satellite class of payloads has been the Scout.[54] LTV's small launcher is capable of putting around 500 lbs into low earth orbit,[55] making it available, but also expensive for a dedicated launch.

2) The second method available is secondary payload. Large satellites do not always meet the launcher's maximum weight capability and room is available for additional mass. In fact, the primary payload manufacturer may find it advantageous to build a satellite smaller than the launcher's capacity, so it can split launch costs with a second or third user. While multiple satellite launches were popular in the past,[56] their use has diminished. As more firms enter the small satellite market, multiple payloads appear to be increasing. Arianespace will be one of the first to again launch a multiple payload as they launch 4 AMSAT and 2 UoSat satellites with the SPOT 2 satellite.[57] The owners of the Delta, Atlas, and Titan are also demonstrating an interest in such capacity,[58] and the planned Conestoga 4 can launch a 12 Get Away Special-can cluster of satellites.

---

[54] The Scout has made 88 launches since 1963. See Pamela Tanck and James Williams, "The Scout Launch Vehicle System", 1988 Utah State Conference.

[55] 219 kg into 555 km circular equitorial orbit, (ibid).

[56] Stacked OSCAR On Scout, for example, a multiple small satellite launch program of Navy Communication satellites from 1985 to 1988.

[57] See G.G. Reibaldi & M. Trischberge, "Ariane utilization - for secondary payloads," 1988 Utah State Conference, p. 7.

[58] See J. Garvey & D. Marin, "Delta II Secondary Payload Opportunities for Tether Demonstration Systems," 3rd International Conference on Tethers in Space (1989) and G.

Secondary payloads may restrict the schedule of the users. Furthermore, some limitation on orbit is imposed on the secondary satellite. Additional requirements may also be imposed because of the primary payload vendor's concerns.

3) One special type of complementary payload is the Get Away Special (GAS)-can available on the Shuttle to commercial and scientific users. GAS-cans are available for up to a 200 lb payload. Many small satellites in the Manufacturer's Table are GAS-can compatible. In addition to the large backlog, uncertain launch dates, and strict safety regulation of the can's contents, the Shuttle puts the payload into an orbit which may not be acceptable to some customers.[59] These factors will naturally restrict GAS-can use.

New launch vehicles, which are being built specifically for the small satellite market, are changing the weight requirements. In the past, the limitations of the Scout put a 500 lb. maximum on the satellites weight. The GAS-can's limit was 200 lbs, and 50 lbs was the typical limit for a piggyback configuration. But newer vehicles, such as LTV's Scout II, Orbital Sciences' Pegasus and SSI's Conestoga, may soon be available to launch greater weights, and government contracts for new small launch vehicles have pushed the weight to 1000 lbs into low earth orbit.

DARPA's Standard Small Launch Vehicle contract, which was recently awarded to Space Data Corporation (an operating division of Orbital Sciences), uses a configuration of a Peacekeeper first stage booster and wingless Pegasus vehicle. It is required to have the ability to put

---

Broad and D. Lynn, "Small Payload Accommodations for the Atlas Family of Launch Vehicles," 1988 Utah State Conference.

[59] Usually 300 km.

1000 lbs into polar orbit. The Air Force's Small Launch Vehicle, a new NASA explorer launch vehicle, and LTV's Scout II also promise to be capable of putting around 1000 lbs into orbit. While none of these vehicles are flying yet, satellite manufacturers have built expectations around them.

Ground stations

Ground stations are an essential complement to any satellite. New ground station technologies for small satellites in low earth orbit are emerging rapidly, and should serve to stimulate the demand for small satellites.

Miniaturization is assisting the mobility of ground communications. Examples include Geostar's hand sized transmitter, part of their System 2C communications system. Furthermore, one of the most successful results of miniaturization -- microcomputers (PCs) -- are now being used for ground control. Recent low budget satellite operations used simple PCs, along with small transmitter/receivers for their complete ground control needs.[60]

Special Natural Resources

The special natural resources involved in space round out the economist's triad of productive factors -- land, labor, and capital. Orbital slots and frequency assignments are still problematic, because they are infused with the "commons" problem.[61] We will not discuss orbit and frequencies in detail, but rather mention a few economically significant problems.

---

[60] E.G., the GLOMR project used an IBM PC XT along with a briefcase sized transmitter/receiver for their ground control station. See GLOMR: Final Technical Report (1986).

[61] See A.S. DeVany; R.D. Eckert; C.J. Meyers; D.J. O'Hara; and R.C. Scott, A Property System Approach to the Electromagnetic Spectrum, (Cato Paper No. 10) Cato Institute, San Francisco, CA, 1980, for one attempt at economic analysis of this area.

If space were more scarce, the basic problem would be keeping spacecraft from colliding into one another. Presently, this is not a problem. However, one similar problem, which is of concern, is orbital debris. Even small particles like paint flakes can damage a satellite. The North American Air Defense Command keeps track of orbital debris, but small particles, usually caused by explosions, are difficult to track. They present a significant problem of space litter.

Another similar problem is electromagnetic interference. Frequency assignments are especially difficult to acquire, given the normal bureaucracy associated with the Federal Communications Commission and the International Telecommunications Union, because of the scarcity of this resource. And once a frequency is assigned, it is still susceptible to interference. Satellite manufacturers offering communications services will encounter many of the issues facing a new terrestrial-based communications project, such as new paging or mobile telephone systems. Many manufacturers of small satellites believe that frequency assignments and interference could represent a real barrier to commercialization.

One significant frequency issue regards the specificity of frequencies and components. Use of the Amateur Satellite frequencies [such as 144-146 MHz and 435-438 Mhz] allows the satellite manufacturer [eg. AMSAT] to use components that are already widely used in the ground-based amateur radio market. Use of such abundant components greatly decreases manufacturing costs and reduces governance complexities; however, by definition, commercial enterprises cannot use amateur frequencies. Other frequencies that have abundant terrestrial-based component use, such as UHF, are also being pursued, especially in Third World countries.

POTENTIAL COMMERCIAL SERVICES

Small satellites are both complementary and substitutable means to provide a particular commercial, scientific, or military services.

In order to properly assess the extent of possible commercial roles for small satellites, it is necessary to look at potential commercial services and products which satellites could provide, large or small, and then determine those segments or customers which small satellites could more adequately service.

There is a vast range of potential applications for satellites -- far more than we can adequately address in this paper.[62] We chose to focus instead on broad market segments, specifically: geostationary communications, low earth orbit communications, remote sensing, location determination, microgravity, academic, scientific, and technology development.

Our approach in each of the seven segments includes our assessment of the potential niches for small satellites, the current market development or maturation of those niches, the advantages and disadvantages of using small satellites for those niches, and potential customers. We have made use of relevant marketing studies where available, and we have examined potential substitutes and complements for each market segment. We have also developed and used leading indicators for some markets.

---

[62] See Appendix E: Satellite Commercial Services.

VI. SMALL GEOSTATIONARY COMMUNICATIONS SATELLITES

Unimpeded by mountains, buildings, and other terrestrial-based obstacles to line-of-sight communications, a satellite in orbit can provide continuous communications coverage to multiple points on earth. One method of providing this service is to put a satellite in geostationary orbit, providing a fixed point in the sky for communications.

Small geostationary satellites can provide the same basic capabilities as large satellites, yet possess fewer transponders. At least four companies are considering the design and manufacture of small geostationary communication satellites: Ball Aerospace, Hughes, BaE/Matra and Israel Aircraft Industries.

The primary potential markets are: (a) smaller countries that cannot afford a large satellite and who prefer owning their own satellite to buying services from Intelsat; (b) a few multinational or large corporations; and (c) companies who want small satellites as gap-fillers, for on-orbit back-up, for initial capability, service restoration or disaster recovery.

Communication satellites are the only commercial space business that have been successful over the last 30 years. In the United States alone there are over $2.5 billion dollars in space-based assets, $1.5 billion in commercial ground assets, and $4 billion in private earth station assets.[63]

---

[63] 1987 figures. See World Space Industry Survey (Euroconsult, Paris: 1988), p.217.

However, while there is a large and potentially lucrative future market for video circuits, the demand for satellite voice circuits within the United States has decreased from 125,000 in 1985 to 30,000 today, and it is expected to decrease further in the next five years.[64] Total capacity is projected to remain at about 500 transponders. This will of course push prices downward. However, some projections show a shortfall in capacity between 1994 and 1995.[65] Small satellites could be used as gap fillers during this time period. In some cases, current pricing may not justify use of a dedicated large satellite.

	Service Coverage			
	Global	Hemispheric	Zone	Spot
Contract Video (preemp)	$ 23,320	15,680	14,670	24,105
Full Period Television				
(preemp)	68,420	39,140	35,265	71,435
(non-preemp, protected)	108,895	91,675 (s)	---	---
(non-preemp,non-protected)	84,135	---	---	---
Full Period Television, cross-strapped (preemp)	---	42,585	48,180	77,895
Datanet (non-preemp)	---	89,950	89,950	
West-East or East-West (simplex,preemp)	79,615	42,585	37,850	75,740
West-West (preemp)	---	45,170	40,430	83,060

Table F: Sample of Charges for Satellite Capacity on Intelsat[66]

Large satellites are providing reduced operator margin and many companies will not build on speculation.[67] Construction and launch costs have risen over the past several years. For some firms, insurance may not be available.[68] A significant portion of this cost may be attributed to overhead costs and managerial inefficiencies. Portions of the existing industry may be pricing itself out of some markets and opening the door for competitors.

---

[64] C.J. Waylan, "Satellite Markets: Opportunities and Challenges," Proceedings from Satellite VIII, (Phillips Publishing, Washington D.C., 1989), p.2.

[65] ibid, p.12.

[66] Monthly rates on 2 year lease contracts. Service is for 1/2 transponder (36 MHz), C-Band jpfor Global, Hemispheric and Zone, K-Band for Spot, 1/2 Duplex, unless otherwise noted. (s) = simplex, (preemp) = preemptible, (non-preemp) = non-preemptible. Source: Regulations and Schedules of Charges for Space Segment Services Furnished by COMSAT (Communications Satellite Corporation, Washington, D.C.,1989).

[67] Jerry Farrell, "Satellite Replacement in the 1990's", Satellite VIII (1989), p.11-12.

[68] ibid.

Australia, Brazil, India, Indonesia, and Mexico have their own domestic space telecommunications systems. China, South Korea, and Colombia have expressed interest in purchasing a domestic satellite system. In addition, regional satellite systems serve a number of countries. These regional systems include the Arab League (Arabsat), Western European Countries (Eutelsat), the Scandinavian Countries (Telex-Notelsat) and the USSR and related countries (Intersputnik). A regional system is currently planned for China and adjacent countries (Asiasat) with a launch scheduled in 1990. PanAmSat, a private venture, is intended to service the Caribbean and adjacent countries. Its initial marketing efforts have met with mixed success.

The developing world has been considering regional systems for years, especially in Africa and South America.[69] Many of the countries in Africa have a relatively underdeveloped telecommunication infrastructure with few telephones, televisions, or computers, and few alternative transmission facilities (microwave or land lines). In fact, many of these countries rely primarily on radio for their communications. Africa and South America have similar problems such as "mountains, deserts, rain forests and large rural populations, [which] complicate the installation of ground equipment."[70] The majority of these countries are considered to be underdeveloped or less developed, with many having high external debts and balance of trade problems.

---

[69] CARISAT is the name given to the satellite project for the Caribbean region nations. CONDOR is the name given to the regional satellite project for the five countries signatories of the Cartagena Agreement: Bolivia, Colombia, Ecuador, Peru and Venezuela. RASCOM is the acronym for the Regional Satellite Communication System for the Development of Africa.

[70] Ospina, Sylvin, "Regional Satellite Systems: Legal and Economic Implications" Satellite VIII, (1989), pp. 5-7.

Although Intelsat has offered its services to these regions, concern has been expressed that this "...would expose the participating nations to unfettered rate hikes and lack of actual control over the satellite telecommunications resources."[71] Similar reservations have been expressed over private entrepreneurs providing regional services. Although a case can be made intellectually for the development of these systems, the probability of these systems being implemented appears bleak. Small satellites for the individual countries may be a workable alternative.

Twenty-five countries have leased, and 15 have purchased, transponders from Intelsat for domestic use.[72] These countries represent targets of opportunity for small satellite communication systems.

Several countries in Europe, as well as Japan, could be considered potential customers for small geostationary satellites. They have, however, their own indigenous capability. With the emergence of the European Economic Community and the Japanese space industry, companies such as MATRA, Aeritalia, Mitsubishi, Toshiba, and Nippon Electric will probably be favored to supply these markets.

Consideration of foreign competition should also take into account opportunities for alternative contractual relationships which provide greater access to potential markets such as the arrangement between LTV and SNIA BPD (Italy) for production and marketing of the Scout 2 launch vehicle,[73] and the agreement between OSC Arianespaces for marketing the Pegasus launch vehicle in Europe.

---

[71] Satellite News, (October 1988).

[72] World Space Industry Survey, p.194.

The small geostationary satellites' success will primarily depend on their cost. If the cost of these satellites in orbit can be made competitive with Intelsat pricing and prices for ground based capabilities, they can significantly penetrate the market. This will probably require a per-unit cost for a transponder in the $2 million-$4 million range.

However, other factors will affect the markets for small satellites. These include financing, insurance, the ability to provide end to end servicing, the system reliability, potential back-ups in the event of failure, and the political, economic, and cultural environments of the individual countries.

Several statistics appear to be leading indicators of the market for small satellites. The main ones are: (a) satellite traffic, which appears to be growing by about 10 percent a year; (b) revenues which appear to be declining; (c) capacity utilization, currently estimated at 75 percent for C band transponders;[74] (d) price, currently estimated at $2 million-$3 million per C band transponder for a six year lease;[75] (e) capital availability, which is currently limited in the developing countries; (f) launch costs, currently estimates range from $16,000 to $50,000 per pound;[76] and (g) the pricing structure of Intelsat and other suppliers.

---

[73] Tanck and Williams, 1988 Utah State Conference, p.5.

[74] Jerry Farrell, (1989), p.12.

[75] Intelsat recently leased 24 C-band transponders from NASA for a period of six years for $51 million. NASA, "Intelsat Selected for Use of TDRS C-Band, (Press Release, September 1, 1989). Sales prices for C band transponders vary between $2.6 million and $4.5 million. World Space Industry Survey, p.194.

[76] Price per pound to geo-stationary orbit.

A satellite system must have well-developed, interconnective and operational terrestrial segments. Population distribution and the availability of terrestrial facilities are two parameters that must be considered.[77]

If a small satellite with adequate capability[78] can be put in geosynchronous orbit at approximately the same total cost per pound as a larger satellite, it enjoys a number of advantages. It is more affordable. A number of countries and organizations can afford $10 to $20 million not $50 million to $100 million. One user could dedicate and control the satellite with all the proprietary rights. The satellite would not be subject to rules imposed by foreign governments or other organizations. These satellites' success of these will depend on reaching geosynchronous orbit at reasonable cost.

A government may want to own its own satellite, rather than depending on a regional system or Intelsat, for a number of reasons: 1) national pride; 2) control of the system; and 3) development of its indigenous space industry. Small satellites may be appropriately sized for some nations, who could get by with a cheaper satellite and fewer services (i.e., fewer transponders). Ideally, regions with light data needs, which are currently serviced by Intelsat's low capacity servicing, could benefit from a dedicated satellite. Intelsat was not set up to handle light capacity demand, so its recent service to these areas, such as the Pacific Islands, is higher priced or suffers in quality (for example, by using preemptive transponders).[79]

---

[77] Sylvia Ospina, "Regional Satellite Systems: Legal and Economic Implications," *Satellite VIII*, p.3. One potential indicator of markets for satellites might be thought to be gross domestic product (GDP) per capita, which would indicate that only the wealthiest nations would be candidates for successful satellite communications systems. This is belied by the fact that two of the three countries with the lowest GDP are among the few countries which have their own satellite systems. These are India and Indonesia. Population dispersion, density, and terrain appear to be much better indicators.

[78] A reduction in antenna size could result in a reduction in equivalent isotropic radiated power. This may be more significant for C band transponders than for Ku band transponders.

The likely candidates for small satellites are: the Andean group of nations in South America, the Pacific Islands, and the African countries. The Andean countries have communications needs that are difficult to satisfy with ground-based systems because of mountains, sparsely settled regions, and political instabilities. Peru in particular has just successfully completed a Rural Communications Service Project, supported by the Agency for International Development's Rural Satellite Program.[80] The experiment was designed to enhance communications in health, education, and agriculture. Rural Satellite Program projects are ripe for small satellites. Pacific Island nations, Fiji, Papua-New Guinea, etc., which have low-capacity needs and a large sparsely settled region. The African countries, which are still studying the RASCOM proposal, are also likely candidates for future small satellite development.

But even in areas that are well-suited for small satellites, American manufacturers still face barriers. For countries motivated more by national pride than real need, resentment toward outside manufacturers is high. These countries want to develop their systems indigenously.[81]

---

[79] Transponders dedicated to an area unless a higher priority need is requested.

[80] See Roberto Aliaga, "Satellite Communications and Social Development in the Rural Areas of the Third World", (Master's Thesis, Georgetown University, Washington, D.C., 1986).

[81] Brazil, Japan, and Israel are all recent examples of locally developed satellite systems.

VII. OTHER COMMUNICATIONS SATELLITES

Fixed position antennas in space (i.e., the geostationary satellite) simplify link-ups, but do not preclude means of communications by satellite. Putting satellites into non-geosynchronous orbits means that one satellite does not continuously cover a particular spot on the ground. Nevertheless, a cluster of satellites can maintain continuous service. Non-continuous coverage, or communications services in a batch mode, are also options.

A typical low earth orbiting satellite can have a period of 90 minutes. With an inclination, the satellite might pass within visible range of a ground location three times in 270 minutes, and then not be visible again for another six hours.[82] So, if multiple satellites were placed, some in the same orbit but lagged behind each other, and some in differently inclined orbits, to continuously canvas an earth location, it is possible that they could maintain continuous communications links. Such clusters can be arranged to provide continuous coverage for the whole globe. Clusters range from 18 Molniya orbiting satellites[83] to 50 low earth orbiting satellites, as proposed by Globesat.[84]

Clusters of small, inexpensive satellites are themselves potentially cheaper than a single, massive geostationary satellite. But total systems costs may still be higher. The crucial factor is launch costs. The 50 satellites will have to go up in multiple, but clustered launches, which may add to the total cost for satellite service. In

---

[82] Data for a typical orbit obtained from GLOMR: Final Technical Report, (1986).

[83] See J. Radbone, "Low Cost Molniya Spacecraft for Navigation/Communications Missions," 1988 Utah State Conference.

[84] See Jane's Spaceflight Directory, 1987.

America, the trend has been toward fewer, but larger capacity launches, so trends will have to change if multiple small satellite launches are to become a reality.

Since low earth orbiting satellites are closer to the earth's surface (300-800 km vs. 35,786 km for geostationary), satellite transmission and reception can be of lower power, and the ground station can be a smaller, omnidirected antenna. If higher data rates are needed, power needs are increased, necessitating narrower beams and more costly requirements for tracking ground stations. The complexity of ground stations can be greater for low earth orbiting satellites than for geostationary satellites.

Continuous global service requires a simultaneous deployment of the whole cluster, but non-continuous service could be a stepping stone to global coverage. One or two satellites could be launched immediately and more added as finances permit. Companies or countries can also lease geostationary service until they incrementally build up their cluster network.[85]

Another method used to provide non-continuous service is a highly inclined elliptical orbit named Molniya.[86] The elliptical orbit places the apogee at nearly geostationary height, so wide areas can be covered while the satellite is in that position. AMSAT's Phase III satellites used such a method. A series of satellites in Molniya orbit can provide continuous coverage with less need for tracking antennas, but with a necessity for high power.

---

[85] Similar to how the new long distance telephone companies started.

[86] Other orbits which could be used include the Apogee at Constant time-of-day Equatorial (ACE) orbit and other sun-synchronous orbits. See Ford Aerospace The Use of Satellites in Non-Geostationary Orbits for Unloading Geostationary Communication Satellite Traffic Peaks, Vol 1-Executive Summary, (NASA, Lewis Research Center, Cleveland, OH), May 1987.

Interactive, near-real time communications service is the norm in the satellite arena, but not all communications is of this form. Communications extends all the way from immediate face-to-face conversation (real time) to facsimile and telex (near-real time), to posting a letter or tossing a bottle into the sea (no timeliness). For example, one particular type of communications -- the sending of computer programs to a central processing unit to be compiled -- can be done interactively or in batch mode.

Store-and-forward satellites, craft with on-board memory (tape players, random access memory, bubble memory, or hard-disks, as used on personal computers), can exploit communications service in the near-real and non-real sectors. A message (or a series of "packets") is sent up to the satellite from the transmitting station, stored in the satellite's memory until it passes over the receiving station, and is then beamed down.

Since communicating in non-real time is considered a lower quality service, its advantage will have to be lower cost if it is to be used at all. Such is the case for batch processing in computers, for batched programs can be compiled at low-demand times (night time) when the central processing unit is not normally in service.

Company	Satellite	Capacity	Type
DSI	GLOMR	256 byte	RAM
Intraspace	T-SAT	12 Mb*	
Univ.Surrey	UoSat2	various	DCE experiment
Naval Postgraduate School	SSDR**	12 Mb	Bubble Memory
VITA	PacSat	4 Mb	Solid State
Arianespace	ARTEF	8 Mb	Solid State
Sweden	Mailstar	8 Mb	Solid State
AMSAT	Microsat	8-25Mb	

* Mb = megabyte.

**Solid State Data Recorder, on GAS-can experiment.

Table G: Memory capacity of recent and planned STORE AND FORWARD satellites

Store-and-forward satellites are beyond the proving stage. GLOMR has been successful, and amateur and university productions have also used this capability. Table H shows some of the applications and needs, that store-and-forward systems can potentially exploit:

Services	Typical BPS	Timeliness	Duration
Vehicular traffic counts & control	<100	Real (or stored)	Full
Hydrographic data collection	100	Near Real	Polled
Utility meter readings	100	None	Polled
remote equip data collection (oil wells, buoys, etc.)	Low	None	Polled
Meteorological	Low	Varies	Polled
Manual input of data to computer (retail store sales, credit verification, etc.)	200	Near real	1 min to several hours
Telegraphy (TTY/Telex/TWX)	24,48,96	None	Tens of secs.
Mailgram	900	None	---
Wire services	96	Near	Full
Voice Data Dissemination (Time, weather, etc.)	300	near real	2 min
Electronic Funds transfer(EFT) from small terminals to node	9600	Near real	---
Retail store inventory manage-. several ment, stocks, new orders	0 - 5600	None (Off hours)	1/2 to hours
Facsimile, interbusiness	1200 - 9600	Near	3-4 min per page
Facsimile Group IV[88]	5600	Near	1 sec per page
Telemetry, scientific and engineering	1200 - 4800	Near	Full
Banking (EFT between banks)	5600	Near real	---
Information retrieval	0 - 5600	Near real	---
Computer graphics and computer aided manufacturing	5600 - 107	Near real	---

Table H: Potential Store and Forward Services[88]

---

[87] CCITT classification for facsimile services

[88] BPS = Bits per second; Polling refers to multipoint data collection; Full is continuous (24 hour demand) that can possibly be broken up. Adapted from Walter Morgan & Gary Gordon, Communications Satellite Handbook, (John Wiley & Sons, New York: 1989), pp. 14-17.

Applications selected for this chart had either non-real or near-real time needs, slower data rate needs since most of these smaller satellites have lower transmitters, and message size in the 10-20 minute or less range. This is the useful time a satellite is visible in a single pass. However, larger messages could be broken into small segments and communicated on successive passes, if they are respliced at the other end after the last packet is received.

Amateur radio operators have pioneered packet radio methods, whereby a radio message is divided into several packets and communicated digitally through a network of radios, repeaters, and other communications stations, to get to its final address. As the store-and--forward concept is further proven, its services could be inserted into the larger communications network.

Potential Users

Batch communications are necessarily inferior to interactive communications. But for some uses, the price of an interactive system is too high. For users that do not require immediate responses, store-and-forward might be the solution. Materials tracking, just-in-time inventorying, remote equipment telemetering, or even electronic mail between dispersed offices of a multinational corporation or international organization could fall into this category.

We have not seen a publicly available study of the potential demand for store-and-forward type satellites.[89] The way to categorize demand for such communications is to typify the potential international users and their needs. Organizations who might use these applications include:[90]

---

[89] Some demand studies have been done on low-capacity demand, usually with proposals for an Intelsat arrangement to solve it. Possibly, some small satellites arrangement can provide for this in a less-costly manner. See Section 5: "Rural and Light Traffic Systems" in the proceedings from the Seminar on Domestic Satellite Communications, (Shanghai, 1983).

Multinational corporations, with offices spread around the world. Orbits will have to be specialized to provide adequate fly-by for a specific company's offices;

Networks of a Multinational industry, like textiles, which may have manufacturing, assembly, packaging, etc., subcontracted in multiple places, and who might benefit from a just-in-time inventorying system, enhanced by satellite systems;[91]

International and Regional agencies, similar to multinational corporations' needs;[92]

Domestic firms in a large country, such as USA, China, the Soviet Union, Indonesia, that store-and-forward could serve; and,

International Professional Associations, such as scientists who need to communicate their work to colleagues in many nations.

The store-and-forward market is just a potential at this stage. But if the transponders' prices increase (because of crowding in the geostationary orbit, or lack of enough new payloads reaching space), a niche may be found for these services.

---

[90] List is based upon users with 1) small or medium capacity data needs, 2) dispersed personnel and 3) needs met with non-real time data response.

[91] Sweden's Mailstar is geared to this demand. See "Viking and Mailstar: 2 Small Satellite Programs", 1988 Utah Small Satellites Conference.

[92] VITA is the entrepreneur in this field. Their store and forward PACSAT with 4mb memory is soon to fly and will provide communications services to their field workers in remote areas of the Third World.

VIII. REMOTE SENSING

A satellite can use its vantage point to observe the Earth. A satellite can have sensors ranging from simple television cameras to sophisticated x-ray devices. The image or data they collect can be digitized and then communicated to Earth for processing. This process is commonly known as "remote sensing."

Optically based remote sensing services are currently furnished commercially by the Landsat System (U.S), SPOT (France), and (USSR). Japan has also launched an earth observation satellite called MOS. They also plan to launch JERS1 in 1992. Data from various meteorological satellites are also consumed commercially.

The government has transferred the Landsat system to EOSAT, a joint venture between Hughes and GE/RCA. The system is heavily subsidized by the U.S. government, which is also the major consumer of EOSAT data. Landsat was limited to 30 meter resolution, thus providing lower quality than the SPOT system (up to 10 meter resolution) and the Soviets' 5 meter resolution. However, a new Landsat satellite (Landsat 6), planned for launch in 1991, will increase the resolution of EOSAT data to 15 meters.

These remote sensing satellites are large. A tradeoff exists between the size and capabilities of remote sensing satellites. Making the optics smaller, for example, results in lower resolution. And reducing the number of different sensing devices, such as altimeters, radiometers, or infrared imagers, reduces the capabilities to provide for co-dependent demand. For example, visual image data is often desired together with infrared data. These contribute to making the current optimal size of remote sensing satellites much larger than small satellites. However, it is possible to reduce the size of current instruments, for example, APL's altimeter, will be a part of the Office of Naval Research's Small Altimeter satellite. Improved computational techniques can also reduce satellite size.

Improving technology, particularly in electronics and power generation can reduce satellite mass. It is also possible to design small remote sensing satellites that are technologically superior to the Landsat system. Small satellite makers should be able to penetrate certain market niches, especially for the military and intelligence communities. The technology for improved resolution is currently available.[93]

Humanitarian services may also be an application for small satellites. The United Nations has used satellites to monitor agriculture, desertification, and natural disasters. Recently, Sweden has proposed that an international body use satellites to monitor disarmament treaties.[94]

The EOSAT customer list indicates existing markets for small satellites in remote sensing. However, the list does not address new, untapped markets, those that might be helped by mass merchandising and repeat sales. The most promising niche for small satellites is customers who have single spectrum data needs that are independent of other spectrum data. An example is the press's desire for improved resolution for their data.[95] There may also be a mass market among homecomers and/or developers for satellite pictures of neighborhoods. Mass marketing may move in to exploit new ideas for sensing data. For example, while the capability exists for higher resolution imaging, there is still a question as to whether policy considerations will permit its use or sale. The current policy states that U.S. firms can provide the necessary capability to be competitive. This has not, however, been put to the test.

---

[93] Mechanisms, including power and pointing, as well as the ability to use existing ground stations, or to provide them at low cost, represent limitations.

[94] For a number of years, the US. and the USSR have used this technology for this purpose.

IX. LOCATION DETERMINATION

Location determination, (i.e., the use of a satellite to report on the location of an object), is similar to remote sensing, but uses different techniques. One particular form of location determination, Radio Determination Satellite Services (RDSS), uses radio signals to locate a transmitter mounted to the object. RDSS is becoming a big growth application in space. Geostar pioneered the commercial application of this service. Combined with short messages (the FCC has allowed Geostar to offer a 256 character messaging service along with location determination), the industry is increasingly using information about the location of a vehicle, shipment, or even person.

Geostar's service is provided from a small payload that is attached to a larger communications satellite located in geostationary orbit. This device receives incoming messages from small transmitters located aboard moving vehicles or other objects. Such transmitters must remain small and simple to be handled easily on the ground. Small transmitters inhibit high-date rate mobile communications such as phone service aboard aircraft, but low data rate services are feasible. After the message is sent up, and the location is calculated, the data are sent down to Geostar headquarters in Washington, D.C., processed further, and sent to the user through regular communications channels.

---

[95] Space Media Network, Stockholm, Sweden currently provides this service. See United States Congress Office of Technology Assessment Commercial Newsgathering from Space (1987).

Although satellite location services only require a small satellite, Geostar currently uses a large one. Another company, Starfind, had proposals for smaller satellites in low earth orbit. The satellites used an antenna that could adjust its angle to find its transmitting objects on earth. Starfind has gone out of business in the United States, but its technology and patents have been sold to Energetics of Australia, to set up radio determination satellite services in that country. Currently, Intraspace is doing fabrication work on the Energetics Starsat using one of their T-Sat standard busses in the 1200-1300 pound class.[96]

The trucking industry has become the biggest user of Geostar's service. Other uses will follow, in what should be a high-growth demand. One application in particular, just-in-time inventorying, shows promise in the near future.

The success of Energetics seems likely, but any small satellite services will face stiff competition from Geostar and its licensed cooperative in Europe, Locstar.

In a slightly different capacity, location determination is useful for navigation. Instead of a remote user being interested in the location of an object, the object itself a ship or plane) desires to know its location. The Navy Transit System is one successful application of small satellites (112 lb) for navigation.[97] However, the pricing structure (free of charge) for this and other navigation systems offered by the U.S. Government (such as NAVSTAR), preclude opportunities for commercial small navigation satellites.

---

[96] See Appendix A

X. MICROGRAVITY

Of all the potential commercial applications reviewed in this paper, none seems as problematic as microgravity materials science (MMS).[98] Microgravity does present the lure of potentially vast commercial markets, but it is shadowed by the usual problems and uncertainties associated with an unproven technology. It is also subject to the constraints of launch vehicles and government policy. It remains to be seen what role small satellites will have in microgravity and whether they will live up to the "hyperbole ... concerning its promise."[99]

Successful microgravity activity does not necessarily mean an increased demand for small satellites. Even if microgravity experiments yield marketable commodities in pharmaceuticals, electronics, and metallurgy, with only limited small satellite applications, they may be performed on a space station or large unmanned satellites, the degree of availability of alternative commercial platforms, and the relative costs of experimenting, processing, and manufacturing in space, and on Earth.

---

[97] See R.J. Danchik, "The Navy Navigation Satellite System (Transit)," APL Technical Digest, 5:323-329 (1984).

[98] Also referred to as materials processing in space (MPS) or materials processing research in space (MPRS).

[99] National Research Council (1988, v); John M. Bryant, Space Manufacturing, (M.S. Thesis, University of Houston, Clear Lake, April 1986) also notes (n.p.) "[MMS] has been exaggerated by overly optimistic forecasts."

Although microgravity experiments began as early as the mid 1960s,[100] the current state of technology for them remains in its infancy. Marketable products based on microgravity research are negligible. Commercialization remains "premature," "embryonic," and in its "genesis."[101]

The National Research Council noted the absence of an adequate pool of knowledge about microgravity research and references have been made to a "[l]imited available base of relevant microgravity R&D."[102] This lack of a technological base on which to develop commercial business lines has led domestic non-aerospace firms like 3M, John Deere, Corning Glass,[103] and foreign enterprises such as the consortium INTOSPACE GmbH, to engage in basic research projects to understand microgravity on a scientific and engineering level before committing the financial and human resources into a capital order necessary to bring products to market.[104] Thus, the assessment that there is "little current interest in direct pursuit of applications" appears justified, as some time will be required before something more substantial than Monodisperse Latex Microspheres appears.[105]

---

[100] United States Department of Commerce, Space Commerce: An Industry Assessment (Department of Commerce, Washington, DC, 1988),p.97; Bryant (1989) also briefly covers MMS history.

[101] The Space Business Research Center, Space Business, August, 1988 (University of Houston, Clear Lake) estimates for 1987 (1988, p.22) illustrate that of the total space industry shipments in dollars, contributions by MMS were insignificant.

[102] Kurt P. Johnson in Molly K. Macauley, Economics and Technology in U.S. Space Policy. (Resources for the Future, Washington, DC, 1986), p.48.

[103] See Jonathan N. Goodrich, The Commercialization of Outer Space, (Quorum Books, Westport, CT, 1989), p.167; United States Department of Commerce (1988, p.99); and World Space Industry Survey (1989, p.326) for listings of manufacturers interested in microgravity.

[104] 3M has entered into a Joint Endeavor Agreement (JEA) - a type of government subsidization - with NASA to fly 62 experiments on STS. United States Department of Commerce (1988, p.101) lists other manufacturers having JEAs with NASA for microgravity experiments.

[105] The 1988 edition of Space Business (The Space Business Research Center 1988, p.21) indicates these ten micron spheres are sold by the National Bureau of Standards. A five milliliter vial is $633, and 89 vials have been sold "for gross revenues of $56,000.

Marketing research indicates that there is insufficient demand for microgravity research to merit commercial interest. In one study,[106] of the 53 user experiments identified, 23 were considered "strong candidate payloads" for the NASA reusable re-entry satellite.[107] However, 80 percent of the 53 were NASA sponsored Centers for the Commercial Development of Space, and only eight of the 23 were payloads less than 150 lbs. Since the weight of the experiment makes up only a portion of the orbiting vehicle mass, eight potential near-term payloads are insufficient reason to develop a small satellite which functions as reusable re-entry satellite.[108] A similar study on the potential for microgravity research and development forecasts limited commercial business in the next five years.[109]

The relationship of microgravity experiments to launch vehicles is critical. One study indicates that many of the microgravity payloads are above the lift capacity of Scout.[110] While this doesn't preclude use of the Atlas, Titan, and Delta, it does require a reassessment of the costs, and perhaps it dictates that the payload be launched as a secondary payload. Of the various commercial applications we have reviewed, microgravity appears to be most seriously affected by the costs of the launch.[111]

---

[106] The Center for Space and Advanced Technology, An Assessment of Commercial Microgravity Science User Requirements for the Reusable Re-entry Satellite -- Final Report (NASA Ames Research Center, n.d.).

[107] Which will be available in 1994. RRS study contracts have been awarded by NASA to GE/Lockheed and SAIC/Sagitta.

[108] The RRS is not a small satellite per se, but its payloads fall within the thresholds we have assigned to small satellites.

[109] Other relevant studies include: Science Applications International Corporation, Small Payload ELV System Study - Phase A Final Review, (NASA Lewis Research Center Contract no. NAS3-25351, September 1988 [hereafter SAIC]); Harvard Business School, Developing Private Sector Programs for Building Space Business (NASA Marshall Space Flight Center contract No. NAG8-569, April, 1986).

[110] SAIC (1988, n.p.).

For microgravity applications, small satellites face several constraints. Many platforms and/or test beds provide recovery capability, and competition from these is increasing. There are several ways to conduct microgravity experiments -- drop tubes and towers, sounding rockets, balloons, aircraft flights, on-orbit satellites, the Space Shuttle, Space Station, and other platforms like the Industrial Space Facility and Spacehab.

A primary consideration is the duration that an experiment requires. The duration ranges from two seconds in drop towers, six minutes in sounding rockets, seven days in on-orbit satellites, to one month on an orbiting platform.[112] There currently appears to be an advantage in the use of small satellites for certain kinds of microgravity experiments, because they provide longer duration for experiments or processing. But there are trade-offs. The capacity of the test bed limits the mass of the experiment. Possible requirements for human intervention preclude the use of small satellites for certain missions. These factors may or may not contribute toward the use of an orbiting platform.

---

[111] See Department of Commerce (1988, p.105); Center for Space and Advanced Technology (n.d.,3); NASA Microgravity Materials Science Assessment Task Force, *Microgravity Materials Science Assessment - Final Report* (Dunbar Report), NASA, Washington, DC, June, 1987); *World Space Industry Survey* (1988, p.323) and Naugle (in Macauley, 1986, pp.70-71). Commercial microgravity payloads represent a temporary market which depends heavily on the availability of the space shuttle and the space station. If there is adequate capacity on the shuttle (as mid-deck payloads, GAS cans, or in the Spacelab) only a limited number of payloads will be flown on expendable launch vehicles in free-flying satellites. When the space station is in operation this market may virtually disappear.

[112] National Research Council (1988, p.40). Comparisons of microgravity facilities are also found in United States Department of Commerce (1988, p.109).

Other issues affecting the decision of which test bed to use are technical (such as forces generated upon re-entry), pecuniary (how much it will cost),[113] and schedule priority and availability of launchers.

A mixed fleet of microgravity platforms means that a potential user may have several flight opportunities, of which a small satellite is only one. Moreover, a microgravity customer can choose from both domestic and foreign test beds. Several nations, most notably the Federal Republic of Germany, offer a variety of test beds -- for example, the Mikroba balloon drop, the MAUS GAS craft, the TOPAS RRS, the Texus sounding rocket, and the anticipated Eureca platform. Other international test beds are offered by Japan, France, China, and the Soviet Union.[114]

Today, the primary vehicles available for microgravity research are the Soviet Mir and the U.S. Space Shuttle with its attached European-built Spacelab.[115] However, because of the Challenger accident, a number of payloads have been waiting to fly on the Shuttle.

In response to the backlog of microgravity experiments, NASA is pursuing plans for development of a reusable re-entry satellite. The reusable re-entry satellite is not a small satellite by definition,[116] but its payloads fall within our definition. The reusable re-entry satellite has historical antecedents from the 1960s. The Discoverer, BIOS, and the Nuclear Emulsion Re-entry Vehicle (NERV) missions demonstrated recovery capability. The reusable re-entry satellite can be launched from an ELV instead of the Shuttle and can carry out a variety of experiments for up to 60 days in 10^{-5}g. Also, the reusable re-entry satellite does not require manned intervention. It may eventually provide lower cost access to space for smaller firms or universities unable to enter into a joint endeavor agreement with NASA.

---

[113] National Research Council (1988, p.48, Table F-1) references how many requirements the experimenter must fulfill prior to flight. This is an example of how flying aboard STS appears to be inexpensive, but actually implies hidden real costs to the user.

[114] United States Department of Commerce (1988, p.104), World Space Industry Survey (1988 pp.329-335).

[115] Both vehicles permit the development of microgravity experiments without the need or costs to develop or provide spacecraft suitable for their use in space.

[116] Although its predecessors Discoverer (340 lbs.) and BIOS (300 lbs.) were.

The market for the reusable re-entry satellite face competition from the Shuttle, the Spacehab, the Space Station.

Whether a sufficient market is available to support reusable re-entry satellites is uncertain. Projections by Bryant[117] indicate that only one-fifth the forecasted experiments will be conducted with suborbital or reusable re-entry satellites between 1989-1994. Because the reusable re-entry satellite is not anticipated until 1994, the availability of opportunities will remain with non-domestic suppliers such as Photon (USSR), TOPAS and Space Courier (West Germany), and SETE (Peoples Republic of China).[118]

XI. ACADEMIC

Throughout the history of space exploration, academic involvement has been prevalent. Satellite demand from academic or other researchers should remain strong, with most of the funds coming from government grants and contracts. Small satellites can capture some of that demand, like they always have, because the small size, combined with a lower cost get-away special, or secondary payload launch, means a less expensive project. Some of the small companies in the small satellite world are specializing in servicing this market, so their marketing style will differ from other commercial offerings, much like the differences Apple has made in its education marketing to the rest of the computer manufacturers.

---

[117] (1989, n.p.)

[118] Finally, the RRS may not be a solution to free up commercial access to space since "[the] existence of two or more independent forms of transportation [does not] solve all of the schedule problems ... if all forms of space transportation are controlled ... by the government" (Naugle, in Macauley, 1986, p.78).

Also, some attempts have been made to sell satellites to universities for student use or to fly payloads developed by NASA's Centers for the Commercial Development of Space. Such payloads are believed to number 20-40 per year. However, many of these may be flown as secondary mid-deck or GAS can payloads on the Space Shuttle. They do not necessarily represent business for the spacecraft or bus manufacturers. A large number of these are microgravity and other payloads, which are dependent on government funding for development and flight opportunities.

XII. TECHNOLOGY DEVELOPMENT

The uses of small craft to develop technology could be a new and growing market for small satellites. Used as a stepping stone to large systems, a small satellite platform is an excellent proving ground for new technology. It is significantly less expensive to develop and test critical technologies with small satellites, than with a standard one. Building and flying a smaller platform is cheaper and does not have to wait for the Shuttle. The turn-around time from design conception to launch is much shorter. LIPS III is a recent example of a small craft used to "provide a test bed for new space power sources."[119] The University of Surrey and Astronautics Inc, also advocate small satellites for technology development. Small satellites will provide numerous testing opportunities in space. Companies inexperienced in space's complexities, but interested in testing their new technology, will find these opportunities appealing.

XIII. ASSESSMENT

In the preceding sections we have focused on specific areas of commercial application. Some general impediments and enabling factors will influence the evolution of small satellites and complementary technologies, regardless of specific applications. We can loosely classify these as "institutional." Two such institutional factors require discussion and elaboration as to the specific ways they impede or facilitate small satellites: the government and the private financial sector.

Regulatory Institutions

Few markets display a greater degree of government involvement than aerospace and defense. In the defense market a common explanation for government intervention, and one which we shall not pursue in this report, is the "public goods" issue -- soldiers, tanks, and ballistic missiles are commodities which every citizen "benefits" from but does not have the incentive to contribute voluntarily towards purchase and maintenance.[120]

---

[119] J.G. Severns, et al., "Experiment Integration on Space Craft LIPS III," 1988 Utah State Conference.

A similar argument may be applied to space. It has been suggested that the results of the United States' involvement in space exploration has led to innumerable benefits for the average citizen. If each person did not contribute, society as a whole would be worse off. Therefore, we cannot depend on markets to provide sufficient investment. Variations of this "market failure" argument point to the special attributes of space as a common resource for mankind, the unwillingness of the financial sector to back capital intensive projects, the non-appropriability of innovations, and the high degree of risk -- hence the reluctance of private entrepreneurs to actively commercialize space.

Were the intervention of government limited to financial patronage of space activities only, we might be tempted to take a Panglossian view.[121] Among the more frequently cited problems we found during our interviews were procurement and quality regulations, erratic funding cycles, exclusion of small businesses, technology transfers, limitations on trade, and the lack of launch opportunities, which we elaborated in our discussion on capital structure. Each of these issues deserves more discussion in itself.

One of the guiding principles of the National Commercial Space Policy Act in 1984 has been summarized as follows, "[i]f the private sector is willing to make the necessary investment, the project's feasibility should be allowed to be determined by the marketplace and the creativity of the entrepreneur rather than the government's opinion of its viability."[122] Small satellites can apply this principle wholeheartedly. Through our interviews we have noticed that, although defense procurement represents the central demand for small satellites in the immediate future, the attitudes and industrial organization of small satellite firms is markedly different from the defense industry. Whether government will impede the development of small satellites remains uncertain. Small satellite technology may fall by the wayside, as it nearly did before, joining, once again, technologies like the hybrid rocket motor rediscovered by AmRoc, or re-entry vehicles rediscovered by the RRS study contract participants.

---

[120] Economists refer to this as the public goods problem. See Tyler Cowen (ed.), The Theory of Market Failure, (George Mason University Press, Fairfax, VA, 1988).

[121] Dr. Pangloss is a character in Voltaire's satire Candide who constantly remarks, regardless of the circumstances that befell him and the protagonist Candide, that this certainly is "the best of all possible worlds."

Much of the small satellites' ability to get a fair test will depend on the degree to which the technology decisions are the result of market decision-making. One encouraging sign is the degree of inter-agency competition for small satellite development.[123] A discouraging sign would be a resurgence of advocacy for a national industrial policy, that is, technological central planning.[124] Such policies rarely help small enterprises over the long haul. Suggestions that the United

---

[122] C.B. Taylor, Jr., *Commercialization of Space*, (Franklin Watts, New York, 1987) p.26.

[123] An economic model based on antitrust activity of the Federal Trade Commission and the Department of Justice indicates that dual enforcement of antitrust statutes results in the two agencies acting more like market competitors than a monopolist. This argument can be extended generally to illustrate the benefits of interagency rivalry. See R.S. Higgins, W.F. Shughart II, and R.D. Tollison, "Dual Enforcement of the Antitrust Laws," pp.154-180 in MacKay, Miller and Yandle (eds.), *Public Choice and Regulation*, (Hoover Institution Press, Stanford, CA 1987).

[124] See for example, David Osbourne, "Business in Space," (*The Atlantic Monthly*, May, 1985); and The Space Foundation (1988). Osbourne acknowledges the demerits of government intervention yet, nevertheless, argues for an explicit "industry policy" between business and government that would stimulate commercial development through large scale subsidization. He believes aggressive federal intervention is needed to challenge Germany, Japan, and make up for the private sector's inability to fund large scale space "infrastructure." He goes on to suggests different ways intervention might occur, e.g., targeting whole technologies rather than specific programs, direct procurement, direct grants, etc.

States should emulate Japan's MITI might find favor among those companies with the resources and employment to catch the eye of legislators, however, small business enterprises may face an even more difficult future in this environment.[125]

One of the themes we heard repeatedly throughout the course of our study was that the technology to build and launch small satellites is mature. While many individuals in private and public institutions continue to push the state of the art outward, the basic requirements to place a satellite on orbit have been developed and refined for more than 25 years. It is perhaps an overstatement to describe satellites as mundane, but not too far over. To the scientist and engineer, and layman, the successful deployment of a payload into orbit no longer evokes awe and amazement. We have come to take such events for granted.[126]

Limitations, trade and technology transfer are also an impediment to the development of the small satellite industry. Export license regulations restrict launch on foreign vehicles. While licenses may sometimes be granted, the time and skills required to secure one are costly, especially to a small business enterprise.

---

[125] Small business enterprise may be successful at securing contracts and funding under a government industrial policy: however, the extent to which SBEs are currently supported should be taken into account to determine the extent to which funds will be directed to such firms. Paul J. Seidman, "An Overview of Small and Disadvantaged Business Contracting," (National Contract Management Journal, 19:1, Summer, 1985 p.10), notes, "federal agencies with annual 'extramural' research and development budgets in excess of $100 million are required to set aside a portion of their R&D budget for award under the Small Business Innovation research (SBIR) programs."

[126] The economist has a different perspective than the engineer or scientist, and what is "mundane" to the latter is "exotic" and a source of academic interest to the former. The former is interested in analysis of the interaction of those individuals and institutions which come to provide products and services (and often overcome seemingly insurmountable hurdles) which pass what Ludwig von Mises (Bureaucracy, New Rochelle, NY: Arlington House, 1969) called "the incorruptible judgement of an unbribable tribunal: the account of profit and loss."

The Financial Institutions

The degree of government intervention in the space economy and the perception that financial markets fail are closely aligned. Financial market failures are blamed on high risk, large fixed costs, and long periods for payback.[127] Rose and others have noted that government, in response to perception of difficulties like financial market failure, skews or distorts the climate adversely.[128] Often this intervention occurs because no financing is forthcoming from the private sector. Because of the extensive list of alternate opportunities available, investors choose projects in accordance with their perceptions of risk and return. That is, the financial markets tell the demanders of capital resources which projects investors are willing to support[129]. The reluctance to support certain projects is often interpreted as market failure, implying that these investors have an incorrect vision of the future.[130] But the decision by government to pursue projects that investors are unwilling to fund results in a restructuring of capital, which may be a failure in itself.[131] It takes investment funds away from more important uses and directs them into less important ones.

---

[127] Arguments in favor of government support for these reasons include The Space Foundation (1988) and Osbourne (1985).

[128] Rose, (in Macauley, 1986, p.102); Samuels, (1985), James Bennett and Phillip Salin, "Privatizing Space Transportation" (March 6, 1987, Reason Foundation, Santa Monica, CA.). Rose mentions that intervention is usually suggested in economic theory based on three market failure arguments: failure of capital markets; non-inappropriately of the benefits of innovations; and distortions caused by pre-existing government intervention.

[129] Samuels (1985) stated, "[Space is not a sacred cow] investors...apply the same sets of standards ... that must be present in any ... financial proposal."

[130] As Brian J. Loasby mentions, "[n]o firm can make investment errors as big as those of governments..." (c.f. Method, Process, and Austrian Economics, Israel M. Kirzner (ed.), Lexington Books, Lexington, MA 1982) p.126.

[131] "It is important to realize, however, that the effects of malinvestment are not confined to the losses of wealth suffered by the capital owners directly concerned and their creditors,

The claim that financial markets fail because space ventures are capital intensive, lengthy, or risky is questionable. Rose cites pharmaceuticals, the development of the IBM 360 system, and Silicon Valley as examples that illustrate private financial involvement that involve risk, long pay-backs, and capital intensity. He also points out that both GE and Westinghouse were able to raise a considerable amount of capital for development, even though these firms ultimately lost money. "There is no evidence that the capital market systematically fails to finance profitable ventures because of high fixed costs, long lead times, or project risk,"[132] Rose concludes. This does not mean, of course, that investors will not make mistakes.[133]

Alternate Technologies

In exploring potential markets, there are costs and benefits of providing a service by means other than those which are being pursued. Besides communication satellites, there are microwaves, land lines, fiber-optics, and underwater cables. Instead of remote sensing, there are ground-based technologies, airplanes, and remotely piloted vehicles. Instead of microgravity satellites, there are drop towers and the space shuttle. These alternate technologies are factors that will influence the commercial success of small satellites.

Technologies Complementary to Small Satellites

For the most part, small satellites face few technological barriers. But some related technologies present important problems and

---

but that through the network of structural complementarity they may extend throughout the economic system" (Lachmann, 1956, p.x).

[132] Rose (in Macauley, 1986, p.99). Small satellites offer the opportunity for innovative financing if a less restrictive institutional climate can be created.

[133] "A progressive economy is not an economy in which no capital is ever lost, but an economy which can afford to lose capital because the productive opportunities revealed by the loss are vigorously exploited." (Lachmann, 1956, 18).

possibilities. These will affect the niches that small satellites will ultimately find.

1) earth stations. For store-and-forward satellites, ground stations must have advanced tracking capabilities,[134] yet they must still maintain small size and affordability. Smaller, cheaper, and "smarter" ground stations are being looked at in remote sensing in order to bring data to the local area more quickly.[135]

2) satellite interlinks. Direct satellite-to-satellite communication can enhance current geosynchronous-located regional communications. Many studies have been done in this area. NASA's TDRSS, satellite network, also incorporates direct satellite communication. For some proposed low earth orbit satellite clusters, such technology will be important.[136]

3) satellite systems. Development of small satellite services will require a systems engineering effort. While the technology required to manufacture and launch small satellites is relatively mature (small satellites do not require any technology unique from that which has been employed on Department of Defense and commercial satellites for the last decade), an integrated system that can perform a service to

---

[134] Mobile ground stations, such as Geostar or on maritime vehicles or airplanes, also have tracking problems, but of a different kind. Mobile antennas must adjust to the moving vehicle, but knows the fixed location of the communicating satellite. The problems associated with this have seemed mostly solved: Geostar is offering a 6" receiver dish, and talks about postage stamp-sized transmitters. But, for LEO satellites, the tracking is of a different kind. The satellite (and maybe even the ground station) is moving constantly. Swedish Space Corporation, with is Mailstar store-and-forward satellite, has mentioned it has solved this problem. Satellites and ground station built in university environments, such as AMSAT's NuSat, also seem to be finding solutions. Starfind also has a unique satellite antenna.

[135] The current Landsat or SPOT arrangement has all sensing data processed at a central site, and then distributed to its users. Immediate access to data (of course, at good prices) could be of benefit to the farmer when surveying his grounds, for example.

[136] Globesat, with its 50 satellites, is an example of such a cluster.

users needs to be demonstrated. This will require a system engineering approach that develops the satellite, the ground support, and the launch vehicle as an integrated system built to meet user requirements. Considering a satellite-based service as a whole, composed of many different segments, is a challenge that systems engineering must address.

No technologies that are unique to small satellites have been identified. New technologies can improve small satellites, and larger satellites could also utilize the new technologies. General technologies that would improve satellites include batteries with higher energy storage per mass, photovoltaic power generation with higher efficiency and longer life, telemetry, tracking and control subsystem with improved on-board processing, recorder, and attitude control.

XIV. CONCLUSIONS

Historically, satellites have been built to meet requirements established by the military, scientific, or business communities. Because of the high cost of launch vehicles, they were increasingly made larger so that economies of scale or scope could be achieved.

Today, satellites have grown so large and expensive that they are not affordable to large numbers of potential customers. The satellites may not be competitive with other terrestrial-based technologies and are high value targets in the event of an enemy attack. They also require long lead times for manufacture and launch.

There has been increasing dissatisfaction in the academic community over the inability to complete projects within the tenure of a graduate student, leading to a debate over large versus small projects. In the military, there has been growing concern over the vulnerability of large satellites, and their inability to provide service to tactical forces. The concern has led to Lightsat and Spinsat initiatives and also to efforts to develop small, mobile launch vehicles.

The problems with large satellites have prompted the development of smaller ones. Both industry and government are investigating potential markets for small satellites.

Over the last ten years, the Radio Amateur Satellite Corporation, the University of Surrey, the Applied Physics Laboratory at Johns Hopkins, Weber State College, and Globesat have studied the technologies and uses of small satellites. A number of entrepreneurial firms have spotted opportunities to build small satellites for the military. These included DSI, Ardak, Astronautics and Intraspace. Today, most spacecraft vendors are considering the small spacecraft business. These include not only U.S. firms such as Hughes, GE, Rockwell, TRW, and Ball Aerospace, but also international competitors such as Aeritalia, BaE/Matra, Israel Aircraft Industries, and Energetics.

In reviewing the potential non-military markets for small satellites, it was clear that seven major categories of activity were being pursued. These were microgravity material processing satellites, geo-stationary communication satellites, communication satellites in other orbits (store and forward, clusters, etc.), remote sensing, position location, academic/scientific, and technology test bed satellites.

Microgravity satellites represent a transient potential market. Studies have shown a potential market of 30-40 payloads per year, not including potential sales to Europe or Japan. Many of these could be flown on the Shuttle, or later, the Space Station, and may not require a satellite. Currently, NASA is funding two study contracts for development of a microgravity re-entry vehicle (Lifesat), based on a capability which has been flown numerous times and is flight-proven.

Small geostationary satellites provide the same capabilities as the large satellites, but require fewer transponders. At least four companies are considering manufacturing or designing them. Smaller countries that cannot afford the large satellites, but that prefer owning their own satellite to buying services from Intelsat, are potential buyers. Some multinational corporations may also purchase their own small satellites.

Communication satellites that are not in geostationary orbit can generally provide specialized low-rate data and delayed batch transmission. But they must compete with other packet switching as well as real-time communication capabilities. In once instance, 50 customers for commercial non-geostationary communication satellites have been mentioned, however, these numbers have not been confirmed.

The success of small, remote sensing satellites depends on the development of firms that are able to deliver final products to the consumer. To be successful, small satellites must compete effectively with Landsat by utilizing more advanced technology and lower prices. There are markets for products available with improved resolution (i.e., one meter or less) and other spectral capabilities. Small satellites have a distinct advantage in the time it would take to have these capabilities available on orbit. Even though current policy permits the use of this technology in order to be competitive in world markets, those with vested interests in the current system and some in the military and intelligence communities may well attempt to delay the necessary approvals.

There have been requests to build small radio determination satellites for position location in order to have a more timely and affordable capability. A niche opportunity appears to exist in this market.

Governments are providing navigation capabilities. Small commercial satellites appear to have a very low probability of success in this market, at least in the near term.

Academic satellites generally depend on the availability of government funding. They can also be launched on the Shuttle. However, as universities move to technology centers, this represents a clear but risky, market niche. A specialized market of providing standard busses should be considered.

Flight test of system components is another market. The commercial market appears to be limited. The government or government-contractor market appears to offer more promise.

If small satellite ventures are to succeed, there must be a change in corporate culture; a clear definition of the products to be sold, the emergence of marketing infrastructure; the identification of competing technologies; and a comprehensive understanding of the related industries capabilities, such as ground stations, tracking telemetry and communications and launch sites and vehicles, as well as operational costs. Marketing plans must be realistic, and take into account social, cultural, geographic, and economic differences.

Internationally, markets in the Pacific region, Africa, and South America appear to offer targets of opportunity. The terrestrial infrastructure, population distribution, terrain availability of capital, capital formation, ability to generate hard currency, regional differences, and each country's sovereign rights are factors which must be considered.

Development costs, risks, and alternative investment opportunities providing a competitive return on investments with commensurate risk are three factors inhibiting the commercial development of small satellites. Government funds are sought as a means of finance for the initial satellite development. Large aerospace firms are, however, taking steps to ensure they will be in a competitive position should the market for small satellites develop. This includes strategic planning, bus design, and/or development.

In summary, pushed by DARPA, Navy and Air Force activities as well as by government budgetary constraints, small satellite capabilities are being put in place which will provide the industry with the capability to aggressively seek new markets at a time when new contracts for large satellites may be diminishing, or becoming less profitable and more competitive.

The industry is poised for this change. Initial activity will be largely based on U.S. military requirements. While studies depict projected demand, these are largely for government payloads and experiments, and are subject to the vagaries of the budget process. It clearly is a time of change and potential opportunity. However, we have not seen evidence that these commercial markets have yet been developed or that the competing capabilities and opportunities have yet been addressed.

XV. BIBLIOGRAPHY

Aliaga, Roberto. Satellite Communications and Social Development in the Rural Areas of the Third World. Master's Thesis, Georgetown University, Washington, D.C., 1986.

American Institute of Aeronautics and Astronautics. AIAA/DARPA Meeting on Lightweight Satellite Systems. Naval Postgraduate School, Monterey, CA, August 4-6, 1987.

American Institute of Aeronautics and Astronautics/Utah State University. Proceedings of the Second Annual AIAA/USU Conference on Small Satellites. Logan, UT; Utah State University, September 18-21, 1988.

Applied Economics Center of Battelle-Geneva. Solid Earth Satellite Market, Cost and Benefits. Final Report, European Space Agency Contract No. 5.756/83/F/FC (SC). NASA Scientific and Technical Information Facility No. N87-11638.

ARDAK Corporation. Global Low Orbit Message Relay Satellite Final Technical Report. September 30, 1986, Report No. ARDAK-8603-01, GLOMR Applications Development Program, ONR Contract No. N00014-86-C-0330.

Booz-Allen, Hamilton. "The Emerging Small Satellite Industry: Opportunities for Innovation." (April 12, 1989), Draft White Paper.

Bennett, James, and Salin, Phillip. "Privatizing Space Transportation." Federal Privatization Project Issue Paper. Santa Monica, CA; Reason Foundation, March 6, 1987.

Broad, G.H., Dunbar, D.R. and Henley, M.W. "Companion Payload Prospects for Atlas Launch." Mimeo, General Dynamics Corporation, San Diego, CA.

Broad, William J. "For Cheap, Versatile Spacecraft, Designers Discover Less is More." New York Times (May 23, 1989).

Browde, Anatole. "Shrinking Electronics Boost Satellite Utility." Aerospace America. (April 1988): 22-24.

Bryant, John M. Space Manufacturing: A Future's Forecast. Master's Thesis, University of Houston, Clear Lake, April, 1988.

The Center for Space Policy. Commercial Space Industry in the Year 2000: A Market Forecast. Cambridge, MA., June 1985.

Center for Innovative Technology. "CIT and OSC Sign Agreement to Construct and Launch Satellite for Use by Virginia." Publicity Release for August 1, 1989.

Cheston, T. Stephen. "Radio Determination Satellite Service." Telecommunications Policy 11:2 (June, 1987): 135-39.

Clapp, H. William. "An Occasion to Mass Produce." Aerospace America. (April 1988).

Communications Satellite Consortium. COMSAT World Systems: FCC Tariff #103. Washington, D.C.; COMSAT, 1989.

DeVany, A.S.; Eckert, R.D.; Meyers, C.J.; O'Hara, D.J.; and Scott, R.C. A Property System Approach to the Electromagnetic Spectrum. CATO Paper No. 10. San Francisco, CA; CATO Institute, 1980.

Emme, Eugene M. Aeronautics and Astronautics: An American Chronology of Science and Technology in the Exploration of Space, 1915-1960. Washington, D.C.; National Aeronautics and Space Administration, 1961. Document No. N79-79471.

Evans, B.G. (ed.). Satellite Communications Systems. Exeter, UK; Pete Peregrinus Ltd., 1987.

Ezell, Linda Neuman. NASA Historical Data Book. (Volumes I-III) Washington, D.C.; National Aeronautical and Space Administration, 1988.

Foley, Theresa M. "U.S. Will Increase Lightsat Launch Rate to Demonstrate Military, Scientific Uses." Aviation Week & Space Technology (September 26, 1988): 19-20.

________. "Space Operations Begin Using Geostar Payload." Aviation Week & Space Technology (July 25, 1988): 55-6.

French, James R.. "Paperwork is a Launch Vehicle Roadblock." Aerospace America (April 1988): 16-18.

Fuhs, Allen E. and Mosier, Marty R. "A Niche for Lightweight Satellites." Aerospace America (April 1988): 14-16.

Goodrich, Jonathan N. The Commercialization of Outer Space: Opportunities and Obstacles for American Business. Westport, Ct.; Quorum Books, 1989.

Grahn, Sven. "Viking and Mailstar: Two Swedish Small Satellite Projects." Mimeo, Swedish Space Corporation.

Harvard Business School. Commercializing MPS: Protein Crystal Growth, The Opportunity, a Business C, and Recommendations. May 1985.

Harvard Business School. Developing Private Sector Programs for Building Space Business. April 29, 1986. NASA/MSFC Contract No. NAG8-569.

Hayek, Friedrich A. von. Individualism and Economic Order. London; Routledge and Kegan Paul, 1949.

Higgins, R.S.; Tollison, R.D.; and Shughart, W.F. II. "Dual Enforcement of the Antitrust Laws," pp.154-180 in MacKay, Miller and Yandle (eds.), Public Choice and Regulation, (Hoover Institution Press, Stanford, CA, 1987).

Hoffman, Eric J. "Lightsats and Cheapsats: The Engineering Challenge of the Small Satellite." Johns Hopkins APL Technical Digest 9:3 (July-September 1988): 293-98.

Howard, William E. III. "Cheaper by the Dozen." Naval Institute Proceedings. (February 1989): 70-4.

Instrumentation Technology Associates, Center for Space and Advanced Technology, Inc. An Assessment of Commercial Microgravity Science User Requirements for the Reusable Re-entry Satellite. Final Report for The Bionetics Corp., NASA Ames Research Center.

Jane's Spaceflight Directory. London; Jane's Publishing Company Ltd., 1987.

Jet Propulsion Laboratory. "Report of the Workshop Panel." Microspacecraft for Space Science Workshop. October 6, 1988.

The Johns Hopkins University Applied Physics Laboratory. Artificial Earth Satellites Designed and Fabricated by the Johns Hopkins University Applied Physics Laboratory. JHU/APL SDO 1600 (Revised) May 1987.

Jones, Ross M. "Coffee-Can-Sized Spacecraft." Aerospace America (October 1988): 36-8.

King, Jan; Riportella, Vern; and Wallio, Ralph. "OSCAR at 25: The Amateur Space Program Comes of Age." QST (December, 1986): 15-18.

Kirzner, Israel M. (ed.). Method, Process and Austrian Economics. Lexington, MA; Lexington Books, 1982.

Lachmann, Ludwig M. Capital and Its Structure. Kansas City, MO; Sheed Andrews and McMeel, 1978 [London; Bell & Sons, Ltd., 1956].

Lang, Derek; Lee, Burton H; and Merrihew, Steven. Overview of Policy, Market and Technology Options for Commercial Reusable Re-entry Satellites. School of Engineering, Small Satellite Program. Stanford, CA; Stanford University, June 15, 1989. Report to NASA Ames, Office of Commercial Programs, Joint Research Interchange Agreement No. NCA 2-333.

Long, Mark. World Satellite Almanac: The Complete Guide to Satellite Transmission & Technology. Indianapolis, IN; Howard W. Sams & Company, 1987.

Lovelace, Alan M. Speech at the World Tech Expo, June 1989. Mimeo, General Dynamics Corp., San Diego, CA.

________. Presentation Before the Defense Science Board, June 6, 1989. Mimeo, General Dynamics Corp., San Diego, CA.

Low-Cost Access to Space, (Proceedings From). Paris, JUne 9, 1989. Shepard Conferences.

Macauley, Molly K. Economics and Technology in U.S. Space Policy. Resources for the Future/National Academy of Engineering Proceedings, June 24-25, 1986. Washington, D.C., 1986.

Masten, Scott E. "The Organization of Production: Evidence from the Aerospace Industry." Journal of Law and Economics 27:2 (October, 1984): 403-18.

Mises, Ludwig E. von. Bureaucracy. New Rochelle, NY; Arlington House, 1969.

Moore, Jesse W. "The Future of Space Flight." The Ninth Annual Dr. Albert Plesman Memorial Lecture (October 26, 1984), Delft, The Netherlands.

Mordoff, Keith F. "Europe Building Its Own Space Business Presence." Aviation Week & Space Technology. (December 19, 1988): 95-7.

Morgan, Walter L., and Rouffet, Denis. Business Earth Stations for Telecommunications. New York; John Wiley & Sons, 1988.

Morgan, Walter L., and Gordon, Gary D. Communications Satellite Handbook. New York; John Wiley & Sons, 1989.

National Research Council, Commission on Engineering and Technical Systems, Space Applications Board. Industrial Applications of the Microgravity Environment. Washington, D.C.; National Academy Press, 1988.

Newell, Homer E. Beyond the Atmosphere: Early Years of Space Science. Washington, D.C.; National Aeronautics and Space Administration, 1980.

Nichols, Robert G. "The Winged Horse." Ad Astra. 1:2 (February 1989): 32-6.

Osbourne, David. "Business in Space." The Atlantic Monthly (May 1985): 45-58.

Payne, Seth. "Starship Enterprise: Chasing NASA's Unfinished Business." Business Week (November 9, 1987): 98-102.

Pickering, W. H. "The Beginnings of the U.S. Space Program." IAF Paper 86-492 (October 9, 1986).

Porter, Richard W. The Versatile Satellite. Oxford; Oxford University Press, 1977.

Purcell, Dick. "Mobile in Orbit." Communications 25:9 (September, 2988): 46-52.

Rawles, James W. "LIGHTSAT: All Systems Are Go." Defense Electronics (May 1988): 64-70?.

Rook, Stuart. "Making it in Space." Director. (UK) 12:2 (September, 1988): 48-51.

Rose, James T. and Stone, Barbara A. "New Initiatives in the Commercial Development of Space."

Rothblatt, Martin A. Radiodeterminism Satellite Services and Standards. Artech House, 1987.

Salomonson, V.V., and Bhausar, P.P. (eds.) The Contribution of Space Observation to Water Resource Management. Pergamon Press, 1980.

Samuels, James P. "Space Commercialization." Statement before the U.S. Senate Subcommittee on Science, Technology and Space, March 14, 1985.

Satel Conseil. Land Mobile Communications Satellite Mission. Task 1 Market Study, European Space Agency Contract No. 6023/84/F/RD(SC), December 1985. ESA Report Reference ESA CR (P) 2302. NASA Scientific and Technical Information Facility No. N87-20462.

Satellite VIII: The Road Ahead. The Eight Annual Conference and Exhibition, Washington, D.C., April 5-7, 1989. Potomac, MD; Phillips Publishing, 1989.

Satellite Communications. International Communications and Broadcasting Conference, London, December, 1985. Middlesex UK; Online International Ltd., 1985.

Science Applications International Corporation. Small Payload ELV System Study, Phase A Final Review. September 6, 1988, NASA Lewis Research Center Contract No. NAS3-25351.

Sedlak, Joe. "PACSAT Prototype Scheduled for Launch in November." VITA News (January 1989): 17.

Seidman, Paul J. "An Overview of Small and Disadvantaged Business Contracting." National Contract Management Journal 19:1 (Summer 1985): 5-19.

Seminar on Domestic Satellite Communications, Shanghai, October 5-12, 1983. People's Republic of China Ministry of Posts and Telecommunications and the International Telecommunications Union, International Radio Consultive Committee.

Shahrokhi, F., Choa, C.C., and Harwell, K.E. Commercial Opportunities in Space. Washington, D.C.; American Institute of Aeronautics and Astronautics, Inc., 1988.

Sheetz, H.J. and Reid, M.S. "Standards for Earth Observations from Space." International Astronautical Federation, IAF-88-107.

Slayton, Donald K. "Small Can Be Beautiful." pp. 107-8 in Space Technology International 1989. London; Cornhill Publications Ltd., 1989.

Space Business Research Center. Space Business. (August 1988). University of Houston, Clear Lake.

Space Policy Study Group, Washington Space Business Roundtable. "Promoting U.S. Leadership in the Commercial Development of Space." The Space Foundation, 21 June 1988.

Space Technology International 1989. London; Cornhill Publications Ltd., 1989.

Stoddard, Rob. "Applications, Today and Tomorrow." Satellite Communications 10:12 (November, 1986): 33-38.

Stuhlinger, Ernst. "First Steps into Space, 1946-1978." Presented at the American Institute of Aeronautics and Astronautics 16th Aerospace Sciences Meeting, January 16-18, 1978.

Sweeting, M.N. "Cost Effective Spacecraft Engineering in Low Earth Orbit Satellites." Pp 385-75 in Satellite Communications Systems. B.G. Evens (ed.). Exeter, UK; Pete Peregrinus Ltd., 1987.

TRW Space and Technology Group. Space Log. 23 (1987). Redondo Beach, CA; TRW, 1987.

Taylor, L.B., Jr. Commercialization of Space. New York; Franklin Watts, 1987.

Thompson, W. David. "Small Satellite Force Enhancement." Mimeo, Small Satellite Manufacturers Association, El Segundo, Ca., 1989.

Turner, Andrew E., and Price, Kent M. "The Potential in Non-Geosynchronous Orbit." Satellite Communications (June, 1988): 27-31.

Unattributed. Applied Microgravity Technology 1:1 (October, 1987): 50-2.

Unattributed. Applied Microgravity Technology 1:3 (July, 1988): 157-60.

Unattributed. "3M Moves into New Research Phase with Polymer Experiment on Shuttle." Aviation Week & Space Technology. (December 19, 1988): 59-61.

Unattributed. "Amsat Pioneers Micro Technology." Satellite Communications 12:10 (October, 1988): 73-4.

Unattributed. "Start-up Rocket Companies Target Small Payloads." Aviation Week & Space Technology (February 15, 1988): 67-8.

United Nations. Space Activities of the United Nations and International Organizations. New York; United Nations, 1986. Sales No. E.86.I.2.

United States Congress, Office of Technology Assessment. Launch Options for the Future: Buyer's Guide, OTA-ISC-383. Washington, D.C.; U.S. Government Printing Office, July 1988.

United States Congress, Office of Technology Assessment. "Alternative Spacecraft Design and Launch Options." Draft Paper. Washington, D.C.; Office of Technology Assessment, May 1989.

United States Department of Commerce. Space Commerce: An Industry Assessment. Washington, D.C., Department of Commerce, May 1988.

United States Department of Justice, Antitrust Division. The Geodesic Network: 1987 Report on Competition in the Telephone Industry (The Huber Report). Washington, D.C.; United States Government Printing Office, January 1987.

United States National Aeronautics and Space Administration. "Our First Quarter Century of Achievement ... Just the Beginning." Press Release 83-132. Washington, D.C.; NASA, September, 1983.

United States National Aeronautics and Space Administration. Aeronautics and Space Report of the President, 1986 Activities. Washington, D.C.; NASA, 1986.

United States National Aeronautics and Space Administration. Spacecraft 2000. Washington, D.C.; NASA, 1987.

United States National Aeronautics and Space Administration. Microgravity Materials Science Assessment - Final Report. (The Dunbar Report), Washington, D.C.; NASA, June, 1987.

United States National Aeronautics and Space Administration. Civil Needs Data Base. Version 3.0, Volume I - Executive Summary. Washington, D.C.; NASA, April 5, 1988.

United States National Aeronautics and Space Administration. Microgravity Strategic Plan - 1988. Washington, D.C.; NASA, August, 1988.

United States National Aeronautics and Space Administration. Pocket Statistics. Washington, D.C.; NASA, January, 1989.

United States National Aeronautics and Space Administration, Goddard Space Flight Center. PegSat-CRRES Science Working Group Meeting Briefing Charts. NASA/GSFC, April 18, 1989.

United States National Aeronautics and Space Administration. Secondary Payload Flight Projection. Washington, D.C.; NASA, July, 1989.

University of California at Los Angeles, Institute of Geophysics and Planetary Physics. Interim Report Compatibility of Payload with the Small Scientific Satellite (S^3). October 9, 1968. NASA Document Accession No. X69-70313.

User Requirements Database. January 1989 from DCA/MSO SETA Recompete Briefing, May 1989

Utah State University. Proceedings of the First Annual USU Conference on Small Satellites. Logan, Ut.; Utah State University, October 7-9, 1987.

Wheelon, Albert D. "The Rocky Road to Communications Satellites." The Von Karman Lecture, American Institute of Aeronautics and Astronautics, 24th Aerospace Sciences Meeting, January 6, 1986.

Williamson, Oliver E. The Economic Institutions of Capitalism. New York: The Free Press, 1985.

World Space Industry Survey: Ten Year Outlook. Paris; Euroconsult, April 1988.

XVI. ACKNOWLEDGEMENT

This report could not have been completed without the assistance and encouragement of a variety of people. The authors wish to expressly acknowledge and thank the following individuals.

At George Mason University's Department of Economics: Professor Jack C. High for his indispensable encouragement and insightful comments during his review and editing of this document; to Mrs. Colleen M. Morretta and Miss Pamela M. Munkacsy for their unflagging support and assistance throughout this project, and to Ms. Annette Kay Rubin, whose indefatigable effort, continued good humor, and helpful comments made the completion of this report a much less arduous effort.

Ms. Char Moss of NASA/Headquarters, who provided - frequently, and often on short notice - countless materials which proved invaluable to our research. The numerous individuals in private industry and government (most of whom we hope to have listed below) whose time and effort in responding to our interview questions, discussing the many-faceted aspects of small satellites, related technologies, and the space industry in general, and providing us with their own perspectives made this report possible. Many of these men and women also provided us with comments on an earlier version of this document; any errors or omissions which remain in the document are the responsibility of the authors alone.

The Center for Innovative Technology, Commonwealth of Virginia, and Michael W. Miller in particular, for actively encouraging this effort and providing the financial support which made it possible.

ACKNOWLEDGEMENTS

Peter Armitage	Space Services Inc.
Ray Arnold	NASA
Harry Atkins	U.S. Senate
Gary L. Bangart	Lockheed
Robert Bartlett	Fairchild Space Company
Kent Beckman	Globesat
Peter Bishop	Space Business Information Center
Drew Bogus	Allied Signal
Mike Brodsky	Lockheed
Gregory Brown	General Electric
Don Brubaker	Rockwell International
Michael Callaham	OTA
Joseph Carroll	Energy Sciences Laboratory
Ken Cejka	LTV Aerospace
Stephen Cheston	Geostar
William Clautice	NRL
James Connor	MCS
Pat Cudmore	Goddard Space Flight Center
Bob D'Ausilio	Intraspace
Richard Daniels	AMSAT
Fred Etheridge	Rockwell International
Rick Fleeter	Astronautics/Argosystems

Gary Garriott	Volunteers in Technical Assistance
John Garvey	McDonnell Douglas
A. Guastaferro	Lockheed
John Grovenor	Argosystems
Steven G. Hadley	Rockwell International
Mark W. Henley	General Dynamics
Eric Hoffman	Johns Hopkins Applied Physics Laboratory
Richard P. Hora	General Dynamics
William Howard	Naval Space Command
Bill Hohwiesner	Fairchild Space Co.
Curt Johnson	Ford Aerospace
Ted Johnston	General Dynamics
Ross M. Jones	Jet Propulsion Laboratory
Bob Kennedy	Honeywell
Jack Koletty	Engineering and Economics Research
Joseph LeBlanc	American Microsat
Richard Little	Booz-Allen & Hamilton
Edward Ludwick	General Electric
Jack Mansfield	Senate Armed Services Committee
Robert Marcellini	Lockheed
Norman McLeod	SpaceAmerica
B.P. Miller	General Electric
David H. Moore	Congressional Budget Office
Rosendo Naranjo	NASA
Lee Q. Niemela	TRW Space Technology Group
Jason O'Neill	Defense Systems Inc.
Dean Olmstead	NASA
John Park	United Technologies
Mike Petzer	General Dynamics
Bob Pincus	Goddard Space Flight Center
Karen Poniatowski	NASA
Duncan L. Reynard	Ford Aerospace
Frank Rotter	Rockwell International
Marco Rubin	Booz-Allen & Hamilton
Dan Sakoda	Naval Postgraduate School, Space
Bill Saavedra	OSC
Jayne Schnaars	Rockwell International
Mark J.Schwene	Hughes Aircraft Co.
Mike Stancati	SAIC
Larry Templeton	Ford Aerospace
W. David Thompson	Spectrum Research & SSMA
Robert Towsley	Naval Research Laboratory
Edward A. Town	Rockwell International
James F. Watson	General Dynamics
Scott L. Webster	Orbital Sciences Corp.
Joseph Wechter	Ford Aerospace

Appendix A: Manufacturers of Small Satellites

Manufacturer*	Location	Product Name	Description[a]	Weight[b]	Orbit[c]	Status	Notes	Reference
Aeratalia	Italy		???			???	for TSS-1	
American Microsat Corp.		AVATAR	general-purpose buses	600 lb.	various	design		"Avatar Small Space .."[1]
Ardak	NoVa	PROFILE[2]	radio sensing	350 lb		design	Office of Naval Research contract. Fairchild sub.	"Navy Building Sats"[3]
Arianespace	France	ARTEP[4]	experiments platform	100 kg	elliptic GTO	fabrication	PATHFINDER demonstration this year	
Astronautics	Reston, VA	Alexis	X-ray telescope satellite	240 lb		design	Los Alamos contract	see [5]
Ball Aerospace	Boulder, CO	BGS-100	communications	350 kg	Geo	design		NY Times article[6]
		BGS-400	Communications		Geo			
		BSS[7]	an all-purpose bus	173 kg	400 km	design		
Boeing			- - -			- - -	potential military bids	
CAST	Weber State College Ogden UT	NuSat 1	small comm satellite	105 lb		operating		"NuSat Update"[8]
CTA	Boulder, CO		small remote sensing satellite			design		
Defense Systems Inc. (DSI)	Mclean, VA	GLOMR[9]	store-and-forward		350 km	operated	also involved in DARPA's LightSAT project	"GLOMR: Final Technical Report"

---

* *this table attempts to represent the collection of experience in the small satellite world. Not all of these busses are intended for commercial use, but given the specificity of ideas, companies may capitalize on ideas they have developed, putting them into commercial use. For many of the satellites included here, no standard data exists for use, weight, or orbit, so typical configurations are detailed for comparative and illustrative purposes only. Data were kept in the units of measurements as initially reported, to minimize conversion, transposition, and other editing errors. Most data were collected from published sources (as indicated from the "Reference" column), but additional data and corrections were gained from interviews.*

[a] for some of the commercially developed busses, many uses are foreseen, so a typical description of application should not be seen as a limit of the craft's applicability. "Potential military bids" is use to indicate companies that have recently re-entered the small satellite arena since Air Force's announcements for proposals, such as STEP and RESERVES.

[b] "Weights" are approximate, and in most cases is spacecraft's total launch weight.

[c] most orbits are circular, unless otherwise specified. Figures denominated in degrees are inclination specifications.

[1] Joseoh A. LeBlanc, "The Avatar Small Spacecraft System", **Proceedings of the 2nd Annual AIAA/USU Conference on Small Satellites** (Utah State University: Sept. 1988) [hereafter referred to as **1988 Utah State Conference**].

[2] Passive Radio Frequency Interference Location Experiment.

[3] "Navy Building Small, Inexpensive Satellites for Launch this Year", **Aviation Week & Space Technology**, (February 20, 1989) p.46.

[4] Ariane Technology Experiment Platform

[5] **International Small Satellite Organization Newsletter**, (June 1989).

[6] William J. Broad, "For Cheap, Versatile Spacecraft, Designers Discover Less is More", **New York Times**, May 23, 1989, p. C1,C7.

[7] Ball Scout Satellite.

[8] Charles Bansall, "NuSat Update", **1986 Get Away Special Experimenter's Symposium**, (Goddard Space Flight Center, Maryland: 1986).

[9] Global Low Orbiting Message Relay.

Appendix A: Manufacturers of Small Satellites

		MAESTRO[10]	comm and sensing	150 lb		fabrication	3 of ONR's SPINSAT project	"Navy Building Satellites ..."[11]
		MacSat	store-and-forward	- - -		fabrication	Scout compatible, for DARPA	
		SECS[12]	comm, for the Navy	140 lb		fabrication	to be integrated with Pegsat[13]	
		X-Sat	standard small satellite bus	150 lb		fabrication	Goddard SBIR contract	"Exceptional Sat. ..."[14]
Fairchild	Germantown	PROFILE				fabrication	Ardak is main contractor	
			- - -			- - -	potential military bids	"Sm. Sat. Mission..."[15]
Ford Aerospace	Palo Alto	(LCSS)[2]		150-450 lb	150 nmi, sun synchronous	defunct		"(LCSS)[2]"[16]
			- - -			- - -	potential military bids	
General Electric		LifeSat	microgravity satellite (with Lockheed)	2700 lb		study	NASA Life Sciences Phase B contract.	
		GE Smallsat	several configs	34 kg	833 km Sun synchronous	study	stats are for sample SSMI[17] mission only	
Globesat	Utah	GS-50	general purpose bus		various	design		
		GS-100	" " "			& fabrication		
		GS-200	" " "			" "		"GS-100 & GS-200"[18]
Goddard Space		SMEX[19]				design		
Flight Center		Pegsat	barium cloud experiments	300 lb	590 km polar orbit	fabrication	For first Pegasus launch	"Pegsat"[20]

---

[10] Multiple Autonomous Experimental Spacecraft for Telecommunications, Recording and Observation.

[11] A.W.S.T. (February 20, 1989), p.46.

[12] Small Experimental Commercial Satellite.

[13] into the first Pegasus launch. see the Goddard entry.

[14] "Exceptional Satellite (XSAT)", (Goddard Space Flight Center, Greenbelt, MD: April 1989).

[15] Robert Bartlett, "Small Satellite Mission Requirements and Concepts", Proceedings from Low-Cost Access to Space (Paris: 1989).

[16] Neil Barberis et al, "Large Capability Small Size Low Cost Satellite Systems", AIAA/DARPA Meeting on Lightweight Satellite Systems (Monterey, CA: 1987) [hereafter referred to as Monterey Mtg.].

[17] Special Sensor Microwave Imager

[18] L.R. Megill, "GS-100 & GS-200: Two Commercial Light Satellites", Monterey Mtg. (1987).

[19] Small Explorer

[20] Robert Pincus, "Pegsat", CRRES Science Working Group Meeting, (NASA/Goddard Space Flight Center: 1989).

Appendix A: Manufacturers of Small Satellites

Hughes	El Segundo, CA					- - -	potential military bids	
		Comm by the Yard				study	Air Force contract	
			3 channel comm	150 lb?	Geo	design	Pegasus compatible, integral upper stage	
Intraspace	Salt Lake City, Utah	SALT[21]	radio sensing	350 lb		fabrication	Office of Naval Research's SPINSAT	
		Energetics[22]	position location	1750 lb		fabrication	for Australia	
		T-SAT[23]	a general purpose bus in four sizes, up to:	GAS size-2500 lb		design & fabrication		"Small Commer. Sat."[24]
Israel Aircraft Industries	Israel	Offeq	experimental	343 lb		launched		
		Amos	communications	750 lb	Geo	???		
Jet Propulsion Laboratory	California Inst. of Technology	L-GAS[25]	extraterrestrial	150 kg	lunar	manufacture	contract from NASA	"L-GAS Spacecraft"[26]
		Lunar Prospect.		600 kg	lunar	design	JPL Quicksat study	"An approach to ..."[27]
Johns Hopkins Applied Physics Lab	Baltimore, Md		several scientific satellites			fabricated		
LCI		Lightcastle	generic busses in several configs	- - -		study	GAS & Scout size	"A family of generic ..."[28]
Lockheed	LA	P-11	small research satellite bus	300 lb		fabricated	AF Discovery series	
Marconi Space Systems Ltd.	England	IMS[29]	communications	700 kg	Geo	study	contract from ESA	"Small Comm. Satellites"[30]

---

[21] Small Altimeter Satellite

[22] Energetics bought all the patents from Starfind Inc., a company now defunct, that was attempting to provide location determination services in the US.

[23] ambitiously named after Ford's Model T.

[24] R.F. D'Ausilio, "Small Commercial Satellite T-SAT", Monterey Mtg. (Monterey, CA: 1987).

[25] Lunar Get-Away Special

[26] K.T. Nock, et al, "Lunar Get Away Special Spacecraft", 19th AIAA/DGLR/JSASS International Electric Propulsion Conference, (AIAA: 1987). Also: K.T. Nock, et al, "An Approach to the Design of a Simple, Radiation Hard, Highly Integrated and Reliable, Lightweight Satellite Bus", Monterey Mtg, (1987).

[27] G.E. Sevaston, D.H. Lehman, K.T. Nock, "An Approach to the Design of a Lightweight Lunar Spacecraft",1988 Utah State Conference.

[28] Jeanine Bowman & Francis Czopek, "A family of generic earth pointing satellites", 1988 Utah State Conference.

[29] Innovative Modular Satellite

[30] J.E. Brown, "Small Communications Satellites", Low Cost Access to Space (Paris: 1989).

Appendix A: Manufacturers of Small Satellites

McDonnell D. Advance Programs Division						- - -	potential military bids	
Naval Post-graduate School	Monterey, CA	ORION	general purpose bus	250 lb	300 km	defunct	works on the Extended GAS	"ORION: A General Purpose ..."[31]
		PANSat[32]	similar to NUSat	150 lb				
Naval Research Lab	D.C.	LIPS-3[33]	solar experiments	138 lb	1100km,60°	operational		"LIPS-III ..."[34]
Orbital Sciences	Fairfax, VA	VaStar	Virginia Satellite	37 lb		fabrication		
Radio Amateur Satellite Corp.	Boulder, CO (for construction)	Pacsat Syncart, LuSat	Microsat busses, amatuer radio comm.	22 lb		fabrication	see[35]	"Amsat Pioneers Micro Technology"[36,37]
		Project DOVE[38]	" " "	22 lb		fabrication	built in conjunction with Amsat/ Brazil	" "
		AMSTAR	Communications	250 kg	Geo	design	a Phase 4 satellite	"OSCAR at 25: ..."[39]
RCA Aerospace and Defense*	Princeton, NJ	MSS	packet-switching communications	199 lb	675-830 km 57° - 80°	study	DARPA's MSSP[40]	"Sat. Bus Design ..."[41]
Rockwell			potential military bids			- - -		
SAIC & SAGITA		LifeSat	life sciences	1500 lb		study	see GE's entry	
Spectrum Research	El Segundo, CA	3 different platforms	general purpose bus	250 lb		design		
		AVHRR	Very High Resolution Radiometer	350 lb	450 nmi Polar Sun-Synchronous	study	in collaboration with ITT Aerospace/Optical Division	"Low Cost Remote Sensing"[42]

---

[31] Aloen Fuhs, et al, "ORION: A General Purpose, Low-Cost Spacecraft", Monterey Mtg, (1987).

[32] Petite Amateur Navy Satellite

[33] Living Plume Shield

[34] Robert Towley et al, "LIPS-III: An Effective & Existing Lightsat", Monterey Mtg., (1987).

[35] Marketing of Microsats by Interferometrics. See International Small Satellite Organization Newsletter, March 1989.

[36] "Amsat Pioneers Micro Technology", Satellite Communications, 12(10):73-74 (October 1988).

[37] also Doug Loughmiller & Bob McGwier, "Microsat: The Next Generation of OSCAR Satellites", QST, p.37-40 (May 1989).

[38] Digital Orbiting Voice Encoder

[39] Jan King, "OSCAR at 25: Beginning of a New Era", QST, January 1987.

* Now GE Astro Space Division.

[40] Multiple Satellite System Program.

[41] H. William Clopp and Leroy Osborn, "Satellite Bus Design for the Multiple Satellite System", Monterey Mtg. (1987).

[42] David Thompson "Low Cost Remote Sensing", Low Cost Access to Space, (Paris: 1989).

Appendix A: Manufacturers of Small Satellites

STARLab	Stanford Univ.	SURFER[43]	ionosphere measurements	150 lb	co-orbit with Shuttle	fabrication	TSS1, Marshall contract, 100 km tether.	
Surrey Satellite Technology Ltd.	University of Surrey	UoSat 1 & 2	general purpose bus,amateur radio comm, experiments		550km sun synchronous	operating		"Cost-effective spacecraft ..."[44]
		Uosat D & E				fabrication	On Ariane launch for this year.	
		UoGAS		150 lb	500 km	design		"UoGAS"[45]
Sweden Space Industry		Mailstar	store-and-forward	123 kg	822 km 87°	design		"Viking and Mailstar"[46]
TRW Space & Technology Group						- - -	potential military bids	
USAF Academy		STARSAT[47]	teaching and research	250 lb		study	for extended GAS-can	

---

[43] Stanford University Radio Frequency Emission Receiver

[44] M.N. Sweeting, "Cost-effective Spacecraft Enginnering in Low Earth Orbit Satellites", in B.G. Evans, ed., Satellite Communications Systems, (Pete Peregrinus Ltd., Exeter. UK: 1987).

[45] Ralph D. Lorenz, "UoGAS - A Get Away Special Satellite with Orbit-Raising Capability", 1988 Utah State Conference.

[46] Sven Grahn, "Viking and Mailstar: Two Swedish Small Satellite Projects", 1st Utah State Small Satellite Conference Proceedings, (1988).

[47] Standardized Teaching and Research Satellite

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
LAUNCHED 1970-1984					
GOVERNMENT - DOMESTIC					
NASA	Explorer 42-46		Scientific	Var./Var./- Var. esp. Scout	(2)
NASA	ITOS-1 (Tiros M)		Meteorology	70/669/TAT-Delta M	(13), 113
USA	TOPO 1		Tactical Survey	70/40/Thor Agena D	(13), 114
NASA	OFO-1		Orbiting Frog Otholith	70/292/Scout	(13), 118
NASA	RAM-C-3		Test of radio blockout	70/101/Scout	(13), 118
NASA	NOAA-1		Meteorology	70/673/TAT Delta	(13), 119
	SAS A,B,C	APL	Small Astronomy	70,72,75/299,387,434/ Scout	(28), V-3, V 11
USAF	Calsphere 3-5		Radar calibration Planetary Atmosphere Experiment Test	71/2.2ea/Thor 71/-/Scout	(13), 120
NASA/Italy	San Marco C,C-2		Scientific	71,74/Var./Scout	(2), B-67,71
Navy	Transit	APL/RCA	Navigation	72-85/Var./Scout	(1); (2)
NASA	ESRO-IV		Scientific	72/253/Scout	(2), B-69
USN	Triad	APL	Experimental	72/207/Scout	(28), I-75
NASA	HEOS A-2		Scientific	72/160/Delta	(2), B-68

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
AMSAT	OSCAR 6,7,8 (Phase II)	AMSAT	Orbital Satellite Carrying Amateur Radio	72,74,78/44,66,44/ Delta	(19)
Spanish Space Org. (INTA)	INTASAT		Scientific	74/33/Delta	(2), B-72
NASA	ANS-A		Scientific	74/272/Scout	(2), B-72
NASA	Hawkeye		Scientific	74/68/Scout	(2)
	GEOS-C	APL	Geodynamics Experimental Ocean	75/750/TAT Delta	(28), II-25
Navy	TIP 2,3	APL/RCA	Transit Improv. Pgm. Navigation.	76/353/Scout	(2); (28), I-85
USAF	P76-5		Communications Propagation Plasma	76/160/Scout	(2), B-74
NASA	Gravity Probe A		Scientific probe	76/224/Scout	(2), B-75
USN	OSCAR II/TRANSAT	APL	Translator Satellite/ Navy Navigation	77/204/Scout	(28), I-95
NASA	HCMM/AEM-A		Appl. Exp. Heat Capac. Map. Miss.	78/295/Scout	(2), B-77
NASA	SAGE		Appl. Expl. Miss. 2	79/280/Scout	(2), B-79
NASA	Magsat	APL	Appl. Expl. Miss. 3 Magnetic Field	79/403/Scout	(2); (28), III-31

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
Navy	Nova I/III	RCA	Navigation (Improved Transit)	81,84/366/Scout	(1); (2), B-80,85
NASA	SME	Ball	Solar Mesosphere Expl.	81/961/Delta	(13), 192
NASA	Dynamic-Explr A/B		Scientific (2)	81/886/Delta	(13), 190
DNA/STP	HILAT	APL	High Latitude Ionospheric Research Sat	83/250/Scout	(2), B-83; (28), IV-21
NASA	AMPTE	APL	Active Magnetospheric Particle Tracer Exp(3)	84/532/Delta	(2), B-85
	CCE (Ampte 1)	APL	Charge Composition Expl.	84/534/Delta	(13), 214; (28), III-39
NASA	ERBS	TRW	Earth Radiation	84/497/STS-RMS	(13), 216
COMMERCIAL - DOMESTIC					
Australis	Oscar 5		Communications	70/33/TAT-Delta M	(13); (19)
Western Union	Westar I-V	Hughes		74-82/-/Delta	(2)
Comsat	Marisat 1,2,3	Hughes	Communications	76/700/Delta	(1); (2)
Western Union	Westar 6	Hughes	Communications	82/660/STS PAM-D	(1)
FOREIGN					
PRC	China 1		Test	70/380/CZ1	(13), 115

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
Intelsat	Intelsat III (F-6,7,8)		Communications	70/544/TAT-Delta	(13)
UK	Skynet II	Ford	Military Comm (3).	70/534/TAT-Delta	(13), 117
France	PEOLE 1		Data collection	70/154/Diament B	(13), 119
FRG/France	DIAL-1-WIKA/ MIKA		Scientific	70/139,114/ Diament B	(13), 114
Japan	Osumi		Test Vehicle	70/26/Lambda 4S-5	(13), 114
NASA/FRG	GRS-B		Scientific	71/70/Scout	(2)
Japan	Tansei		Scientific	71/136/Mu-4S	(13), 120
PRC	China 2		Test	71/486/CZ1	(13), 121
NASA/France	CAS/EOLE		Meteorology	71/220/Scout	(2), B-67
France	Tournesol 1			71/212/Diament B	(13), 121
UK	UK-4,X4,5,6 (Ariel)		Scientific	71-79/Var./Scout	(2), B-67,71,72,79
Canada	ISIS 2		Ionospheric Studies	71/580/Thor-Delta	(13), 121
NATO	NATO-2	Ford	Military Comm. (2)	71/534/TAT-Delta	(13), 120
Canada	Anik	Hughes	Communications (3)	72-75/-/Delta	
FRG	AEROS,B		Scientific	72,74/275/Scout	(2)

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
ESA	COS-B		Cosmic Ray	75/610/Delta	(2)
NASDA/Japan	GMS 1,2,3,4	NEC/Hughes	Meteorology	77-89/~670/N-2	(13), 214
Japan	Kiku-2	MELCO/Ford	Exp. Comsat	77/-/N-2	
CNES/France	Signe 3	Matra/CNRS	Gamma Rays, Solar UV	77/225/Soviet	(1)
Japan	Tansei 4		Scientific	80/294/Mu-3S	(13), 181
India	Rohini 1,2,3		Earth Resources	80,1,3/83-92/ SLV-3	(13), 184, 203
India	Bhaskara 2		Earth Resources	81/976/C-1	(13), 193
International	UoSat-1,2	U. Surrey	Scientific/	81,84/110/Delta	(19); (13), 192, 211
Amateur Radio	(Oscar 9,11) (Phase I)		Communications (incl. VITA DCE in '84)		
ISAS/Japan	ASTRO-A (Hinotori)	NEC	Astrophys. res.	81/401/Mu-3	(1); (13), 187
ESA	CAT 4		Test equip.	81/477/Ariane	(13), 194
Japan	ETS-3 (Kiku 4)		Scientific	82/858/N-1	(13), 199
NASDA/Japan	Sakura 2A,2B	MELCO/Ford	Communications	83/770/N-2	(1)
Japan	ASTRO-B (Tenma)		X ray observer	83/407/Mu-3S	(13), 202
International Amateur Radio	Amsat-Oscar 10 (Phase III)	AMSAT N/A, DL	Communications	83/550/Ariane	(13), 205

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
UK	UKS (Ampte 3)		Scientific	84/169/Delta	(13), 215
NASDA/Japan	Yuri 2A,2B	Toshiba/GE	Communications	84,86/770/N-2	(1)
NATO	3D	Ford	Military Comm. (4)	84/704/Delta	(13), 217
ISAS/Japan	EXOS-C (Ohzora)	NEC	Magnetosphere study	84/396/Mu-3S	(1), (13), 210
USSR	Cosmos series		Various	Various/~200/Var.	(1)
USSR	Vega 1,2		Halley's Comet		(30), 90
LAUNCHED 1985-1989 GOVERNMENT - DOMESTIC					
SDIO	CRO	DSI	Chemical Release Obs	8?/-/STS-GAS	
DARPA	GLOMR	DSI	Global Low-Orbit Message Relay/ <1 M.	85/150/STS-GAS	(2), B-88; (13), 226; (21)
Navy	SOOS 1-4	GE	Stacked Oscars on Scout Navigation	85,87,88/Var./Scout	(1); (2), B-87,89,90
Navy	Navstar II		Navigation	85/359/Atlas E	(13), 225
N. Utah U.	NUSAT-1		Air Traffic Control	85/114/STS-GAS	(2), B-86; (3), 133
			Radar Sys. Calib.		(13), 220
DNA/USAF SD	Polar Bear	APL	Polar Beacon Exp. & Auroral Research	86/243/Scout	(3), 133; 28, IV-29

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
NASA	AEROS	Ball/ Space America	Earth resources	86/436/- STS	(1)
Navy	LIPS-3	NRL	Living Plume Shield	87/138/-	(7); (16), 213
	GOES 7	Hughes	Geo. Envir.	87/880/Delta	(13), 234
USAF	STACKSAT P87-2	DSI	Coll. magnetomtr data	87/400/Atlas	
Navy	Nova II		Navigation	88/375/Scout	(2), B-90
International Amateur Radio	Oscar 13 (Phase III)	AMSAT	Communication	88/550/w Meteosat, Panamsat/Ariane 4	(13), (19)
NASA/Italy	San Marco D/L(S)		Science	88/600/Scout	(2)
NASA/Goddard	MMMS	Fairchild			
COMMERCIAL - DOMESTIC					
Geostar		GE Astro-Space	Mobile Tracking Sat. (3)	-/-/wGTE GStar	(8)
FOREIGN					
ISAS/Japan	MS-T5(Sakigake)	NEC	Halley's comet	85/265/M-3SII	(1); (4), 141
ISAS/Japan	Planet A(Suisei)		Halley's comet	85/265/M-3SII	(1); (4), 141
ISAS/Japan	Astro C		Halley's comet	85/265/M-3SII	(1); (4), 141

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
International Amateur Radio	Oscar 12 (Fuji) (Phase II)	JAMSAT/NEC	Communications	86/40/-	(19)
NASDA/Japan	JAS-1	NEC	Com. Sat. Amtr. Rad.	86/110/H-1A	(1)
Sweden	Viking	Saab/Boeing	Scientific Sat. 106 (M. SwK)	86/1161/Ariane 1	(4), 127, (9)
ISAS/Japan	Astro C(Ginga)		Scientific	87/924/Mu-3SII	(13)
Intospace/FRG	Cosima		Microgravity	88/44'/Long March 2	(23), 95
Israel/ISA	Horizon (Offeq)	Israel Aircraft Ind. (IAI)	Experimental	88/343/Comet	(24)
U. Rome	San Marco-5	U. Rome		88/-/Scout	(4), 112
CONTRACTS AWARDED NOT LAUNCHED *GOVERNMENT - DOMESTIC*					
Amsat		Weber State AMSAT/(CAST)	CAST Microsat	89/~22/ w/SPOT 2 on Ariane (UoSat D,E)	(10)
VITA		Weber State AMSAT/(CAST)	PACSAT	(Ibid)	(10)
NASA/DARPA	PegSat/SECS	GSFC/DSI	Pegasus tesT/Navy Exp. Barium Experiment	90/300,150/Pegasus#1	(29)
Navy	MacSat	DSI	S&F Comm. (2)	90/-/Scout	

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
Navy/ONR	Spinsat/Profile	Ardak/ Fairchild	Passive Radio Freq Interference Location Experiment	90/-/Scout	(7); (18a), 2
VITA	PACSAT A,B	U. Surrey	Packet Radio Comm.	90/-/-	(20)
DARPA	ASTP/LightSAT	DSI	Advanced Space Technology Program. UHF Repeaters/$7.4M 7 Microsats	91/400/ Pegasus #2	(7)
USAF(STP)/ DoE/Los Alamos	ISES/Alexis	Astronautics	X-Ray telescope	91/240/Pegasus	(18a), 3-5
NASA/MSFC	CRRES	Ball	Combined Release & Radiation Effects (10)	91/5@520,5@850/ Scout & ?	(7)
NASA/MSFC	TSS/Surfer	Stanford U. STARLab	Tethered Sat Sys./ Stanford U. Radio Freq. Emmission Receiver	91/150/STS-HH-G	(16), 78:230 (26), Dill, et al
Navy/NRL	Spinsat/SALT	Intraspace	3.2 M./T-Sat	92/400/Scout	(18a), 2
NASA/GSFC	GGS	GE Astro	Geospace Global (2) $50M	92/-/-	(14), 6
USAF		DSI	3 Chemical Release		(15); (18), 2
NASA/GSFC	XSat	DSI	Exceptional Satellite GAS Compatible bus/$0.5M	-/-/STS-GAS	
Navy/ONR	Maestro	DSI	Communication/Sensing	-/150/Scout	(25); (3)

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
USAF	Small MilSatComm	Hughes, GE, Stanford Telecom	"Comm. by the Yard"	Study	
USAF	MSS	Contel/RCA	Multiple Sat Sys. Pgm.	2 year study	
NASA	L-GAS	JPL	Lunar GAS	-/330/STS-GAS	(16), 21
NASA	LifeSat	GE Astro	Reusable Reentry/ life sciences missions	-/-/Taurus	
?	SEDS	MacDac	Tethered Sat.		
SDIO			SELR	Study Phase Only	(7)
DARPA/USAF	MSSP	Various	Multiple Sat.Sys.Pgm. (Cancelled)		
CIT-Virginia	VaStar	OSC	Communications (1)	-/35/Pegasus (Secondary)	(27)
NASA/Langley		Globesat	Definition Study		
AMSAT	Phase 4	CAST	Mockup complete GEO Communications	-/550/-	
COMMERCIAL - DOMESTIC					
Geostar		GE Astro F	RDSS	90s/-/STS	(8)
FOREIGN					
Sweden	Mailstar	Saab/Boeing	S&F Comm./(2)/ 30M SwK (1986)	88?/270/Long-March 2	(4); 128, (9)

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
Argentina	LuSat	Weber State AMSAT/CAST	Amateur Radio	89/~22/w Spot 2 on Ariane (UoSat D,E)	(10)
UK	UoSat-D,E	U. Surrey	Experimental	89/-/w/SPOT 2, Ariane	(18b), 1
FRG/Italy	TOPAS	NIS Space Ltd.	Transport operation for Microgravity payloads assembled on Scout	89/264$^{@}$/Scout	(22), 51
ISAS/Japan	EXOS D		Earth plasma obs.	89/660/Mu-3S-2	(1); (4), 141
ISAS/Japan	Muses A		Scientific	89/660/Mu-3S-2	(1); (4), 141
Brazil	Missao Espacial Completa Brasileria (MECB)		Data Collection (2)	89,91/253/VLS	(4), 180-1
Brazil	Dove	Weber State AMSAT/(CAST)	Amateur Radio	89/~22/w/spot on Ariane (UoSat D,E)	(10)
ESA/France	Ulysses	Consortium	Scientific 160 (M.86 ECUs)	90/770/- Shuttle-IUS-PAM D	(1); (4), 78
ISAS/Japan	Solar A		Scientific	91/-/-	(4), 150
Italy		Aeritalia	Sat.for NASA/MSFC TSS $120 M	91/-/STS	(4), 113
Brazil	MECB		Remote Sensing (2)	92/374/Chinese	(4), 181

APPENDIX B - CUSTOMERS & CONTRACTS FOR SMALL SATELLITES (~<1000 lbs.*)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
Israel/ISA	AMOS	IAI/Dornier	Aircraft Mediterranean Orbital Sys. Comm. Sat. (2)	- /- /-	(24)
NOT CONTRACTED - ANTICIPATED PROGRAMS					
GOVERNMENT - DOMESTIC					
USAF-STC	TAOS		RFP due F89	-/-/Pegasus	
USAF-SDXR	Reserves	Boeing, Lockheed, ARDAK	Study Contracts	92/150-400?/SLV	
USAF	STEP	TBD	Class C/25-35M		
GSFC	SMEX		Small Explorer		
DARPA	ASTP	Hughes		-/200-400/-	
COMMERCIAL - DOMESTIC					
Unisys		Globesat	Store & Forward	89/167/Amroc ILV	(11), 99
Geostar			Digital Mobile Sat. 80M(90),138M/sat.(92,3)	90,92,93/-/-	(8)
AMSC (American Mobile Satellite Corp.)		TBD	Mobile Comm. Sat. ~100M	RFP issued 7/15/89 for '93 launch	(12)
		Globesat	Gravity Gradient Sat.	-/-/GAS	(15)

CUSTOMER/ LOCATION	CONTRACT/ NAME	MANUFACTURER/ PRODUCT	DESCRIPTION/(NO.) VALUE ($)	DATE/LBS./ LAUNCH VEHICLE	REFERENCES (REF No.) Page
FOREIGN					
Energetics/Australia		Intraspace	LEO Position Location (6)	91-2/-/-	
Sweden	FREJA			-/-/Long March	

* Weight indicated is launch "wet" weight

@ Payload only

1 Aviation Week and Space Technology, (March 20, 1989): 187-9.

2. NASA Pocket Statistics. January 1989. National Aeronautics & Space Administration, Washington, D.C.

3. Aeronautics and Space Report of the President, 1986 Activities National Aeronautics & Space Administration, Washington, D.C.

4. World Space Industry Survey. 1988 Edition Paris; Euroconsult, 1988.

5. Pace, Scott. "Space Transportation Costs." (June 24, 1988): 4.

6. Jones, Ross M. "Coffee-can Sized Spacecraft." Aerospace America (October, 1988): 36-8.

7. Aviation Week and Space Technology (September 26, 1988): 19.

8. Aviation Week and Space Technology (July 25, 1988): 55-6.

9. Grahn, Sven. "Viking and Mailstar: Two Swedish Small Satellite Projects." Proceedings of the 1st Annual USU Conference on Small Satellites, Logan, UT; Utah State University, 1987.

10. Satellite Communications (October, 1988): 73-4.

11. Business Week (November 9, 1987).

12. Aerospace Daily (June 2, 1989).

13. Space Log 23 (1987). Redondo Beach, CA; TRW Space and Technology Group.

14. Satellite News (January 2, 1989).

15. Fuhs, Allen E. and Mosier, Marty R. "A Niche for Lightweight Satellites." Aerospace America (April 1988): 14-16.

16. Proceedings, AIAA/DARPA Meeting on Lightweight Satellite Systems, Naval Postgraduate School, Monterey, CA (August 4-6, 1987).

17. Jane's Spaceflight Directory 1987, London: Jane's Publishing Co., Ltd., 1987.

18a. International Small Satellite Organization. (March, 1989).

18b. International Small Satellite Organization. (June, 1989).

19. King, Jan; Riportella, Vern; and Wallio, Ralph. "OSCAR at 25: The Amateur Space Program Comes of Age." QST (December, 1986).

20. Sedlak, Joe. "PACSAT Prototype Scheduled for Launch in November." VITA News (January 1989): 17.

21. Ardak Corporation, Final Technical Report, No. ARDAK-8603-01, September, 1986.

22. Applied Microgravity Technology 1:1 (1987).

23. Aviation Week and Space Technology (December 19, 1988): 95-7.

24. Military Space, (September 26, 1988).

25. Aviation Week and Space Technology, (Feb. 20, 1989): 46.

26. Proceedings of the 2nd Annual AIAA/USU Conference on Small Satellites, September 18-21, 1988.

27. Center for Innovative Technology Publicity Release for August 1, 1989. "CIT and OSC Sign Agreement to Construct and Launch Satellite for Use by Virginia."

28. Artificial Earth Satellites Designed and Fabricated by the Johns Hopkins University Applied Physics Laboratory, (JHU/APL SDO 1600). Laurel, MD; Applied Physics Laboratory (May, 1987).

29. "Pegsat-CRRES Science Working Group Meeting." Briefing charts, NASA/Goddard Space Flight Center (April 18, 1989).

30. ESA Bulletin 38 (May, 1984).

APPENDIX C - Launch Vehicles & Launch Options

VEHICLE/ DESIGNATION	MANUFACTURER	STAGES	#TO LEO(POLAR)/GTO/GEO	EST.COST	STATUS	REFERENCES
Domestic						
Astra A	E' Prime Aerospace	?	900/400/-	10		
Astra B	E' Prime Aerospace	?	35,000/12,000/-	60	Proposed	
Atlas/I	General Dynamics	2	13,000/5,150^9/1,750	55	Operational	(B)
Atlas/II	General Dynamics	2	14,950/6,100^9/2,500	TBD	Jan.'91	
Atlas/IIA	General Dynamics	2	/6,400^9/	TBD	Production	
Atlas/IIAS	General Dynamics	2	19,000/8,000^9/	TBD	Production	(A) Broad & Lynn
Conestoga II	Space Services, Inc.	?	1,131/xx/xx	15	Design	
Conestoga III	Space Services, Inc.	?	2,264/xx/xx	17	TBD	
Conestoga IV	Space Services, Inc.	?	3,091/xx/xx	20	TBD	
C-130 (Black Brant 5)	Conatec					
DELTA 3920	McDonnell Douglas	3	7,600/2,800/1,450	40	Operational	
DELTA II 6925	McDonnell Douglas	3	8,780/3,190/1,600	45	Oct. '88	
DELTA II 7925	McDonnell Douglas	3	11,100/3,190/1,350	??	June, '90	
ILV-S	American Rocket Co.	3	1,210(968)/xx/xx	7.5	Development	
ILV-1	American Rocket Co.	3	5,390(3,520)/660/xx	12	Development	
Liberty 1	Pacific American	3	449/xx/xx	5	Development	

APPENDIX C - Launch Vehicles & Launch Options

VEHICLE/ DESIGNATION	MANUFACTURER	STAGES	#TO LEO(POLAR)/GTO/GEO	EST.COST	STATUS	REFERENCES
Liberty 2	Pacific American	2	449/xx/xx	5	Development	
LPLS	Lockheed	?	1,100/xx/xx	8	Development	
Pegasus (Air Launched Vehicle)	OSC/Hercules	3	900(600)[11]/xx/xx	10-14	Development Launch NOV/1989	
Scout G-1	LTV	4	440[6,7]/xx/xx	10-15	Operational Since 1963	(A) Tanck & Williams
Scout II	LTV/SNIA BPD (Italy)	4	990[6]/ /	15	Proposed 1993	(ibid)
Titan 34D	Martin Marietta	2 3	26,000/-/- -/-/4,200		No Longer Available	
Titan II	Martin Marietta	1	4,200/xx/xx		July, 1988	
Titan III	Martin Marietta	3	27,600/8,600/4,200[2]	140	mid '89	
LEO	Eagle Canyon Research					(A), Sakota
Titan IV	Martin Marietta	3	40,000/-/-		Operational	
STS- Shuttle			65,000[1]/52,500[2]		Operational	
STS-C			100-150K/-/20,000[4]		Proposed 1993	
ALS (Advanced Launch System)	TBD				Proposed by USAF for late 90's	
ALS	Third Millenium		150-200K/-/-		Proposed 1995	
SLV	USAF Academy	2	550[5]/-/-		Demonstration only	

APPENDIX C - Launch Vehicles & Launch Options

VEHICLE/ DESIGNATION	MANUFACTURER	STAGES	#TO LEO(POLAR)/GTO/GEO	EST.COST	STATUS	REFERENCES
(Small Launch Vehicle)					Proposed 1990	(A), Nici & Chun
Taurus Standard Small Launch Vehicle (SSLV)	OSC/Hercules	4	-/-/-	15-16	Development First flight 6/91	Sat.News 7/10/89, 7
Super Starbird	Space Data Corp.		3,700(3,000)/830/450			(A), Sakoda
Start	Space Commerce Corp./ Technopribor (USSR)		300[13]/-/-	4-5	Proposed for test 1993	AWST 8/7/89 pg.21
Foreign						
LittLEO (Small orbiter)	General Technology Sys/ Royal Ordance		(440)/-/-			(B)
Ariane 3 (Arianespace)			-/5,690/2,780		Out of Production	
Ariane 4 (Arianespace)		3	17,600/4,180-9,260/4,800	78-104	Operational Since 1988	(A), Reibaldi, et al
Ariane 5/L-5 (Arianespace)			-/11,880/-			(B), 38
Ariane 5 (Arianespace) Hermes Spaceplane		?	46,200/14,960/7,750	??	Proposed 1995	
M-3 S II (Japan)	ISAS/Nissan					
M-3 S III (Japan)	ISAS/Nissan					
H-1 (Japan)		3	-/2,300/1,210	??	Operational	
H-II (Japan)	Mitsubishi	2	17,600/9,000/4,000 -/	100	Development Available 1992	

APPENDIX C - Launch Vehicles & Launch Options

VEHICLE/ DESIGNATION	MANUFACTURER	STAGES	#TO LEO(POLAR)/GTO/GEO	EST.COST	STATUS	REFERENCES
Long March 2C(China)	Great Wall Ind.	2			Operational	(B)
Long March 3 CZ-3 (China)		3	-/3,000/1,433 -/5,500/2,500	30	1988	
VLS/SONDA (Brazil)		4	440[12]/-/-		Development 1990	(B)
Shavit (Israel)	IAI		550/-/-			(B)
Long March 4 CZ-2E (China)		3	20,000/8,800/4,000	30-35	1990 First flight 1991	
Long March CZ-3E (China)		3	xx/6,000-11,000/xx	??	1993	
Polar Satellite Land Vehicle (India)		4	-/-/-		Planned 1990	(B)
Augmented SLV (India)		5	330/-/-		Development	(B)
Geosynch. SLV (India)		4	-/-/-		Planned 1995	(B)
Proton/D1 SL13 (USSR)		3	44,000/10,000/4,800	30?	Operational	
Shuttle (USSR)			66,000/-/-		Operational	
Soyuz (USSR)						
Cyclone (USSR)		3	8,800/-/-			
Energiya (USSR)			220,000/50,000/-		Development Tested 1987	
SL-3 (USSR)			13,900/			

APPENDIX C - Launch Vehicles & Launch Options

VEHICLE/ DESIGNATION	MANUFACTURER	STAGES	#TO LEO(POLAR)/GTO/GEO	EST.COST	STATUS	REFERENCES
SL-4 (USSR)			16,500/			
SL-6 (USSR)			4,600/			
SL-8 (USSR)			3,800/			
SL-11 (USSR)			8,800/			
SL-12 (USSR)			43,000/			
SL-13 (USSR)			43,000/			
SL-? (USSR)			12,100/			
SL-16 (USSR) Space Plane			33,000/			
Kosmos (USSR)		2	1,000/-/-		Operational	

1 180 miles
2 300 miles
3 TOS
4 Centaur
5 160nm. 28' orbit
6 555 km circular equatorial orbit
7 165 kg into 555 km circular polar orbit
8 13,200 into ??
9 w/ 11ft. payload Fairing
10 400 nm
11 250 nm
12 500 km equatorial
13 500 km
14 400 nm polar

(A) 2nd AIAA/USU Small Satellite Conference (1988)
(B) Space Technology International 1989 pp.19-24

DRAFT LIST OF QUESTIONS TO ASK INDUSTRY/MANUFACTURING REPRESENTATIVES
6/14/89

1. In your view, what are the fundamental uses of satellites?

   Limiting factors? - optical technology?

2. *What is your company's involvement with satellites/smallsats?*
   - define smallsats (SS)

   - if not involved, why not?
   - Are you aware of PanAm Sat, Peru, Dominican Republic.
   - What were the circumstances that made it successful?
   - GEOSTAR-are there similar types of applications?

   - if involved, why?
     - contracts: past, present, future
     - company literature available?

   - What do you know about microsats?
   - Potential/current launch vehicle mfrs.?

3. Do you envision any commercial feasibility for SS in the near or distant future?

4. With SS what are you selling? Information? Access to space environment?

5. Who do you envision as potential customers (domestic and foreign) for SS services?

6. What technological advancements/changes are required or would facilitate SS development?

7. What are the relative advantages of largesats vs. ss and vice versa?

8. What are the cost drivers on large satellites-size/weight, power, antenna, micro-miniaturization, survivability req'ts.?

9. Are there any special market niches for SS?
    - by function
    - by customer
    - for particular lat./long.

10. Can any current sats be downsized to fit small launch vehicles (i.e., <1000 lbs.)?

11. Can you provide current relative cost figures (by lb.?) for sats and launch vehicles? How do you expect these costs to change over time?

12. Do you believe launch vehicles are a relevant concern in the SS arena?
    - what launch options do you envision by 1992 for SS?

13. What institutional hurdles have you faced (or anticipate) in commercialization of space and/or development of SS? How did you get around them?
    - procurement environment and funding
    - financing
    - insurance
    - technology transfer
    - consortiums/ teaming/ joint ventures

14. Do you think SS will be procured by the DoD?
    - When?
    - Which programs?

15. Is Govt. procurement necessary to stimulate commercial applications
    - Space in general
    - SS in particular

16. What ROI would you expect from a SS venture?

17. *Can you suggest other sources of information?*

- Contact name/org./phone

14. What are (will be) the approximate weight(s) of your spacecraft?

15. What are the orbital requirements for your spacecraft?

16. Are clustered launches of 2 or more spacecraft acceptable for your requirements?

17. Approximately what cost per pound (kilogram) do you expect to pay for your launch requirements?

18. What amount, if any, are you willing to pay for a dedicated instead of a companion launch?

19. What percentage of difference in launch costs would you pay for the reliability of an established versus a new launcher?

20. Does your spacecraft use liquid or solid propulsion for large velocity maneuvers?

21. Do you require any special support requirements after launch?

22. Do you require or envision multiple launches? How many?

23. Have you conducted any marketing surveys?

VIRGINIA'S CENTER FOR INNOVATIVE TECHNOLOGY

Established in 1984 by the General Assembly, Virginia's Center for Innovative Technology is the operating arm of the Commonwealth's Innovative Technology Authority. CIT's mission is to advance economic growth through use of the state's technology resources in support of technology development. CIT invests in research with commercial potential at state universities, assists in commercializing that research, and aids in the creation and support of technology companies in a variety of ways.

With headquarters in a landmark facility near the Washington Dulles International Airport, CIT has funded more than 450 research projects involving more than 400 companies at state-supported colleges and universities. This research is conducted in many areas, including fiber optics, biotechnology, computer software and information technology, materials science, power electronics, magnetic bearings, and C^3I.

CIT is leading Virginia's space enterprise development effort, and manages a number of programs and initiatives with commercial space orientation. These include: the *VaSTAR* small satellite technology development and applications demonstration program; a small satellite communications ground station development project; a demonstration and prototype development project involving innovative applications of remote sensing technology; a spaceport user needs and impact assessment; the development of s space business incubator; and others.

CIT is the managing agency of the Virginia Space Development Consortium. The Consortium leverages the research capabilities of Virginia's universities in support of research of interest to its member corporations and agencies worldwide. CIT is also a participant in the Virginia NASA Space Grant College Consortium, and the Virginia and Washington Space Business Roundtable organizations.

For more information about CIT's space research and development programs, contact:

Stephen L. Morgan, *Director*
Space Industry Development

Michael W. Miller, *Director*
Technology Commercialization

CIT Tower, Suite 600
2214 Rock Hill Road
Herndon, Virginia 22070 U.S.A.
(703) 689-3023

ANNOUNCING THE PUBLICATION OF A RECENT STUDY

AN ASSESSMENT OF POTENTIAL MARKETS FOR SMALL SATELLITES

Lawrence Stern • Kevin Lacoble • Zenon Zygmont

Virginia's Center for Innovative Technology is pleased to announce the publication of the first title in its *Space Research and Development Series*. An Assessment of Potential Markets for Small Satellites is the final report of a study sponsored by CIT through the Center for the Study of Market Processes, Department of Economics, George Mason University. A brief overview of the study was presented at the 3rd Annual AIAA/USU Conference on Small Satellites in September 1989.

~~The study addresses~~ A number of economic and technological issues associated with the dynamic field of small satellite systems and applications are addressed. The study describes current activities in the design and development of small satellites, and assesses potential commercial markets for these satellites and their services. The research includes a history of the small satellite industry, current activities of satellite manufacturers, support services for small satellite systems, including launch vehicles and ground control, potential users of small satellites, the availability of various enabling technologies, and other factors which might enable small satellites to be commercially successful. Also addressed are the potential difficulties of small satellite development and production.

Based upon an extensive overview of existing literature, and in-depth interviews with the entire breadth of the industry, this study represents ~~the most~~ up-to-date information regarding this growing area of commercial space activity.

The text is paperback, perfect bound, and is 90 pages in length, comprising 15 chapters and several appendicies. The cost of $15.00 per copy covers our production costs and postage in North America. (Overseas addresses, please add $5.00 per copy for airmail delivery.) The study, completed in September 1989, will be available in November 1989.

NAME: ____________________

ADDRESS: ____________________

____

____

PHONE: ____________________

NO. OF COPIES: ____________________
($15.00 each)

Mail to:

Virginia's Center for Innovative Technology
CIT Tower, Suite 600
2214 Rock Hill Road
Herndon, Virginia 22070

Make checks payable to:
Center for Innovative Technology

Virginia's Center for Innovative Technology

AMOUNT ENCLOSED: ____________________